Lung Volume Updates- 2023

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Objectives

01

List the 4 lung volumes and 4 lung capacities and how these are measured by body plethysmography and nitrogen washout techniques.

02

Review the latest updates on lung volume measurements from the ATS/ERS.

03

Describe quality control standards.

Why Were Standards Updated?

2005: Last published ATS/ERS lung volume standards

- Hardware and software updates, new research and best practices influenced the changes

Goal for standardization = reduce variability

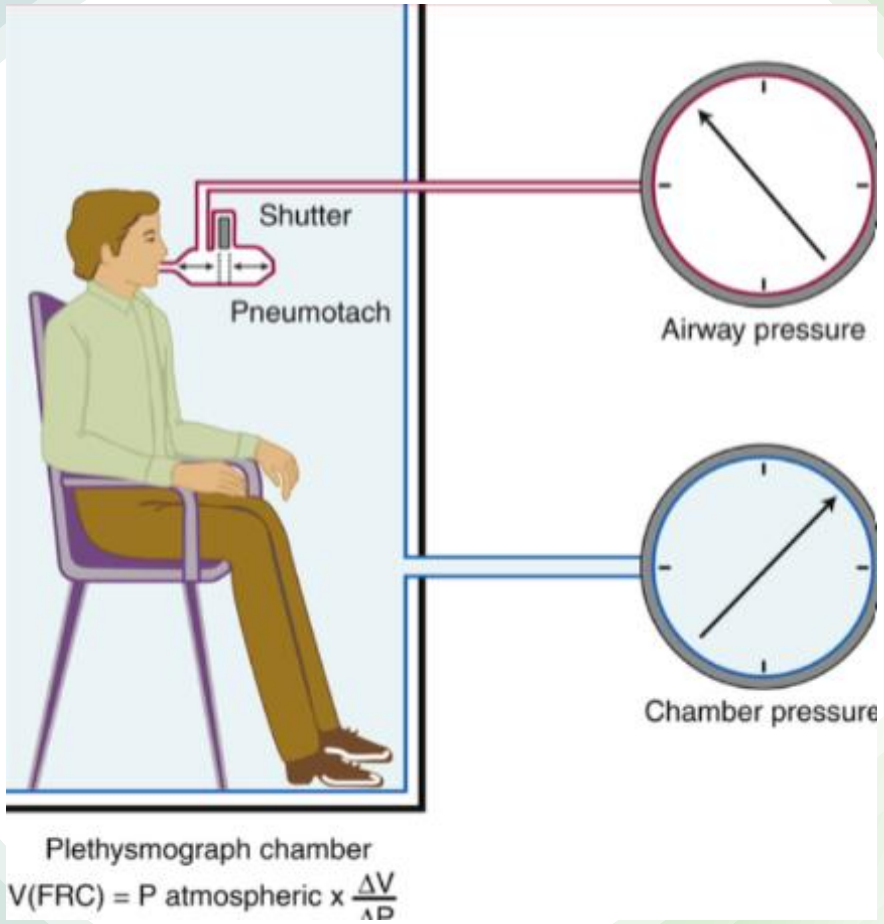
- If PFT labs perform the test the same way, results should be similar between sites

Lung Volume Review

- Body Plethysmography
- Dilution Techniques
  - Nitrogen Washout
  - Helium Dilution

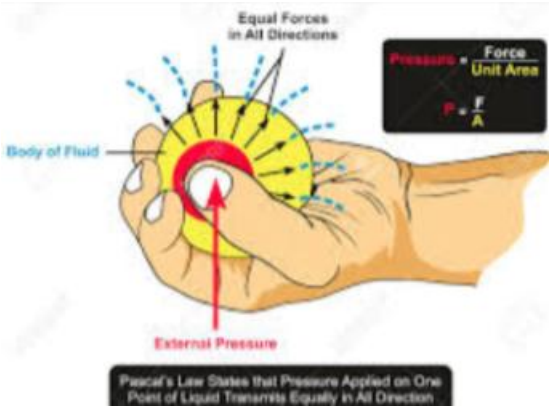
Body Plethysmography

- The most accurate and preferred method of measuring lung volumes.
- As the patient breathes against a closed shutter, pressure changes are measured in the box and at the mouth.



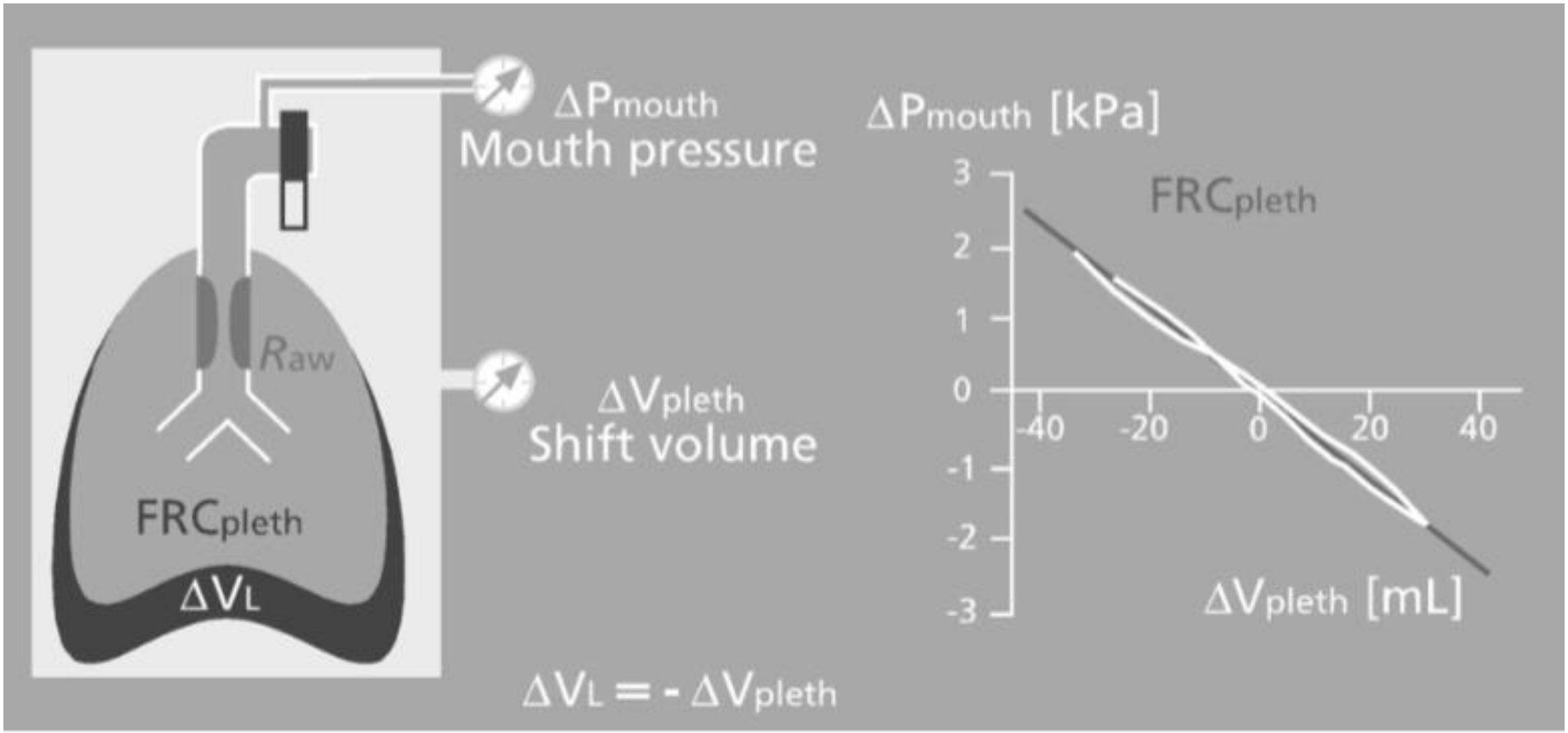
How This Works

- Pascal's Principle- In a fluid or gas filled circuit, pressure at any point is felt equally throughout the circuit



- Boyle's Law- The pressure and volume of a gas have an inverse relationship. If volume increases, then pressure decreases and vice versa, **when the temperature is held constant**.


NCSSM
Online


ΔPmouth
Mouth pressure
ΔVpleth
Shift volume
Raw
FRCpleth
ΔVL
ΔPmouth [kPa]
FRCpleth
3
2
1
0
-1
-2
-3
-40
-20
0
20
40
ΔVpleth [mL]
ΔVL = - ΔVpleth

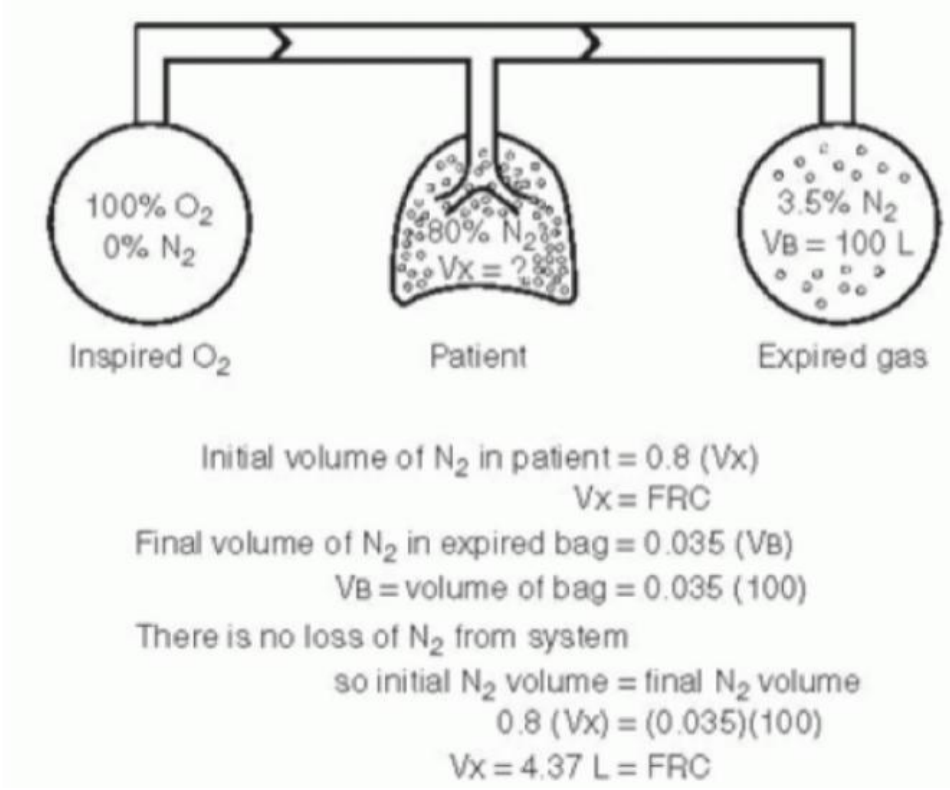
Dilution Techniques

Nitrogen Washout

May underestimate LV

FRC is washed out of the lung by breathing 100% O2 to replace N2 from the FRC

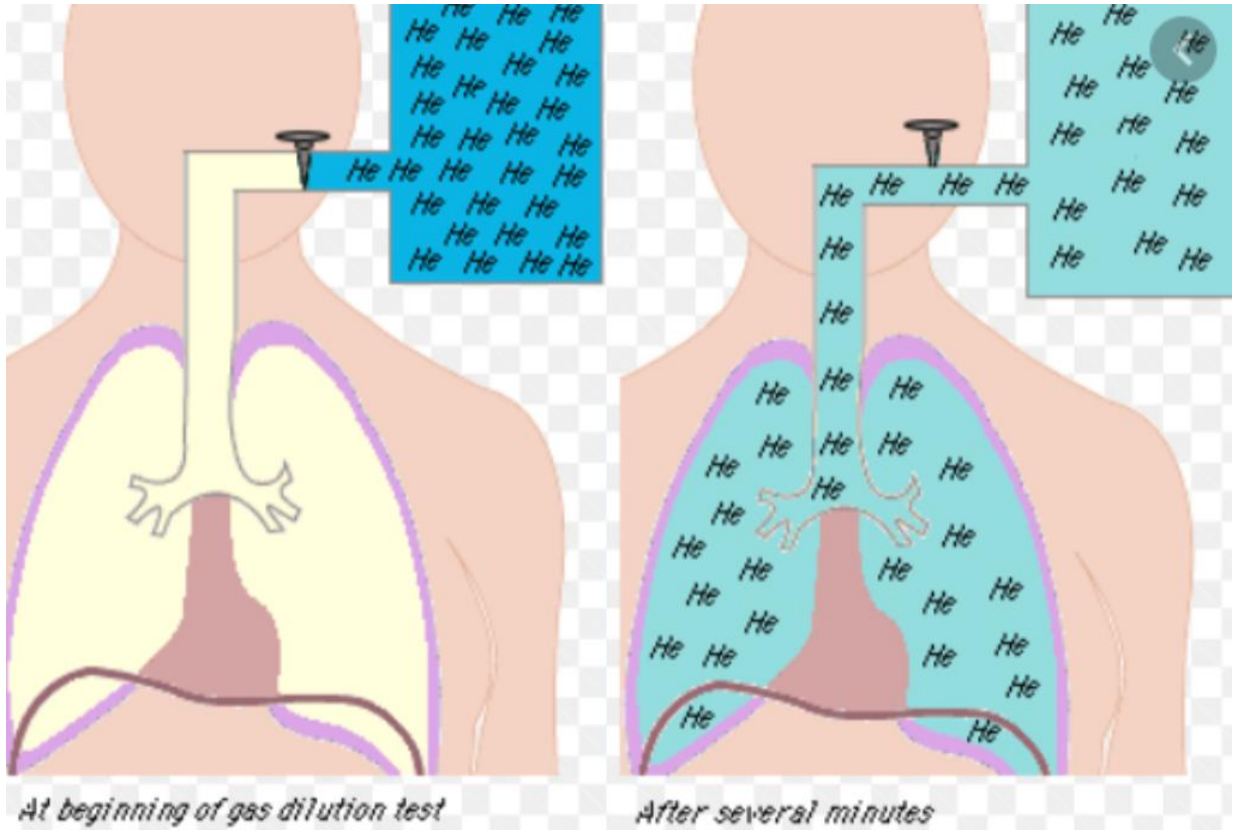
The amount of N2 removed is used to calculate the FRC



Dilution Techniques

Helium Dilution

- May underestimate LV
- The sample gas in the system (helium) equilibrates with zero sample gas in the lung
- He gets diluted with FRC gases and the FRC volume is calculated by the degree of dilution of the He.
  - Switch in must occur at the end of a tidal breath (@ FRC)



Key Updates

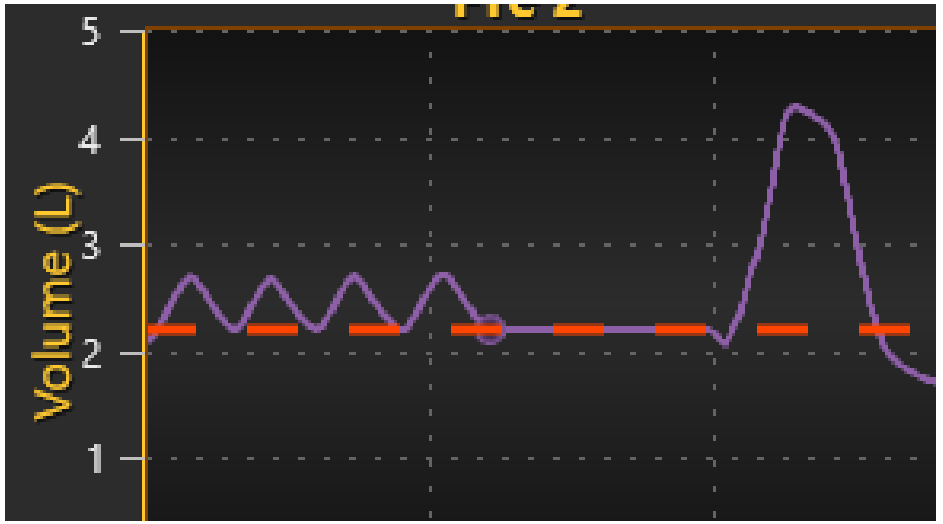
- Linked maneuvers after FRC is measured
- Acceptability and repeatability criteria
- Importance and limitations of biologic quality controls for quality assurance
- Equipment QC and validation recommendations
- Emphasis on pant frequency and recommendations on measuring airway resistance

Body Plethysmography

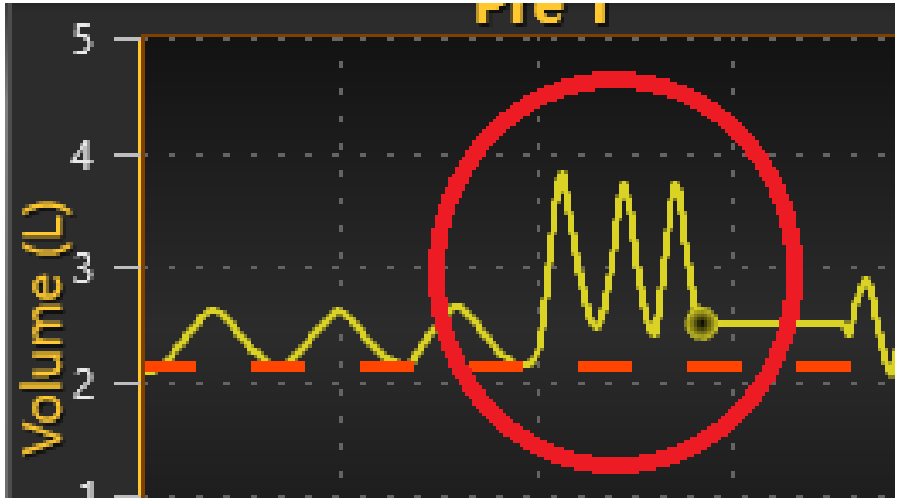
- Verify a stable end-tidal pattern pre-shutter closure
    - Do not “pace” their breathing pattern
    - Look for a relaxed, rhythmic breathing rate
    - Irregular of fast breathing will not allow accurate FRC to be measured
        - FRC is effort ***independent*** if the patient is relaxed

Ensure a Relaxed Breathing Pattern

- Relaxed



- Not Relaxed



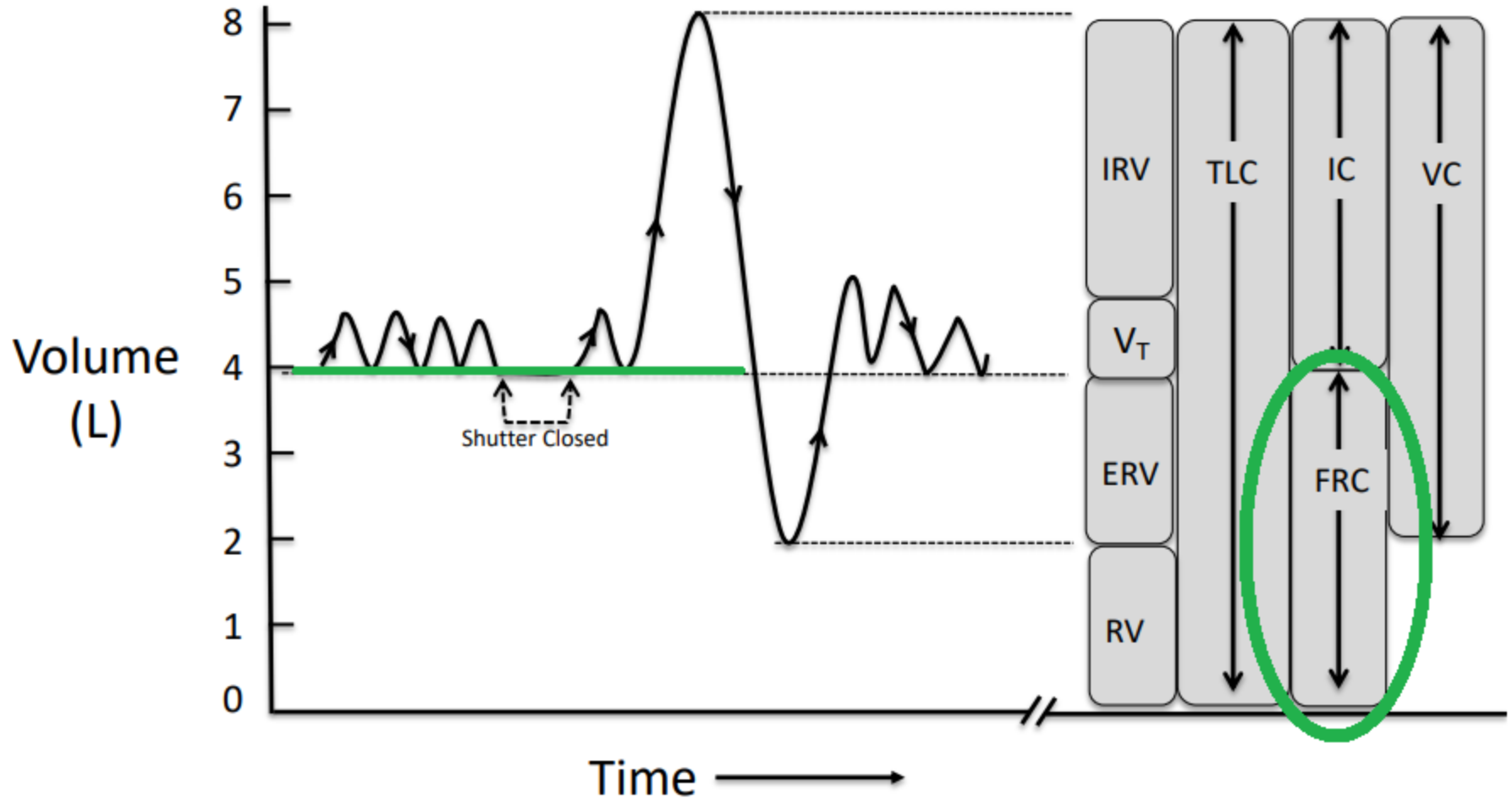
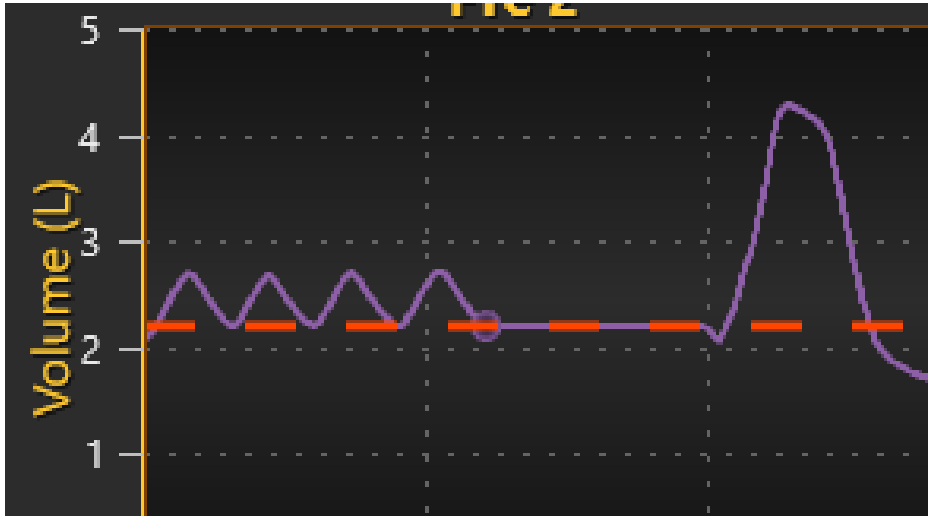
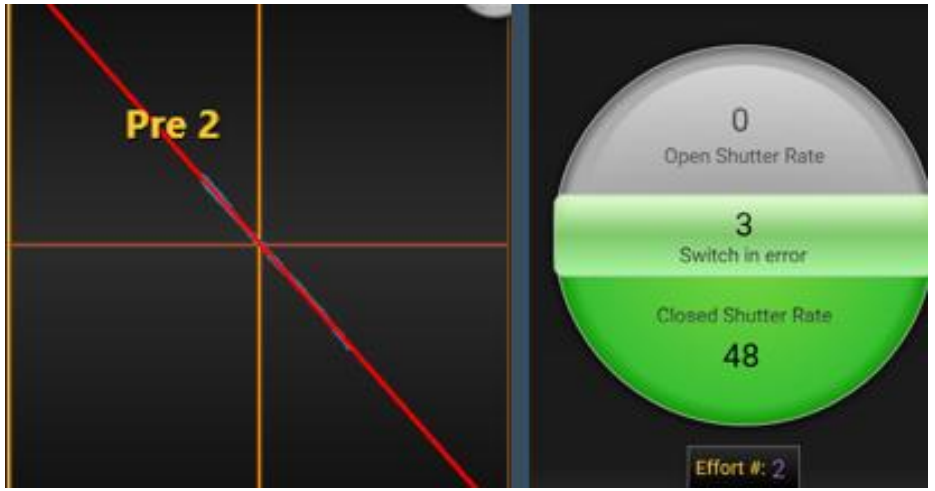


Figure 2: Volume–time display showing the sequence of quiet breathing and, after stable end-expiratory level is achieved, a short period when the shutter is closed for determination of the thoracic gas volume, followed by an open-shutter period during which the patient stays on the mouthpiece and performs an inspiratory capacity (IC) manoeuvre followed by a slow expiratory vital capacity manoeuvre. In a linked manoeuvre, all volumes are determined without the patient coming off the mouthpiece. FRC: functional residual capacity; IRV: inspiratory reserve volume; V_T: tidal volume; RV: residual volume; ERV: expiratory reserve volume; TLC: total lung capacity.

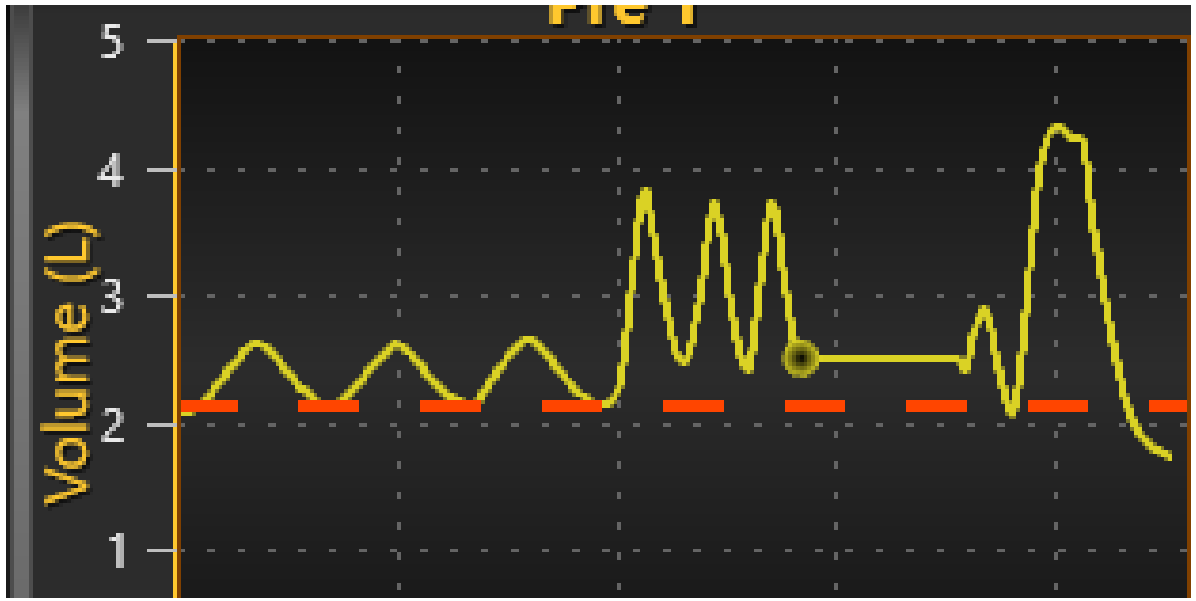
Shutter Closure Timing

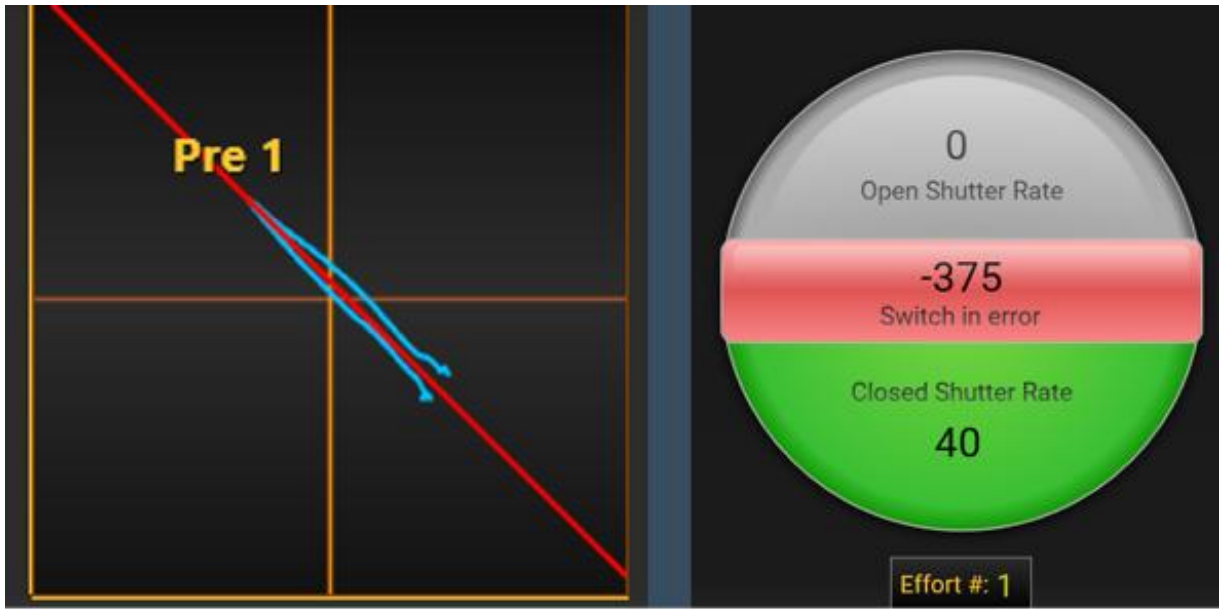
- This occurs at FRC
  - At the end of a normal, tidal breath
  - Ensure that you obtain closed loops
  - Obtain overlapping straight lines with no or minimal thermal drift
  - Pant frequency: 0.5-1 Hz = 30-60 bpm

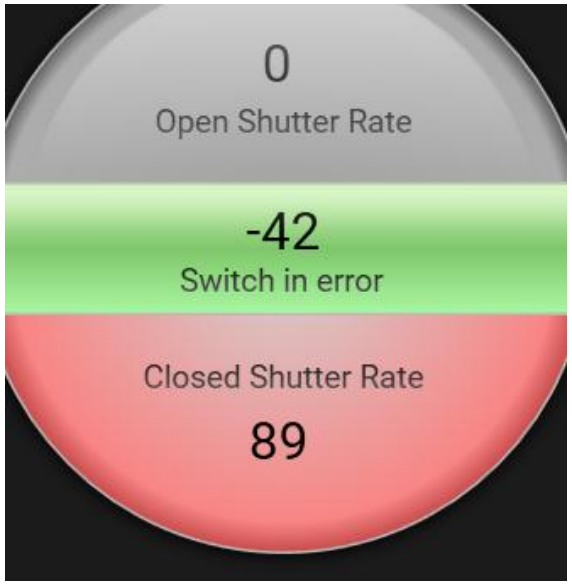


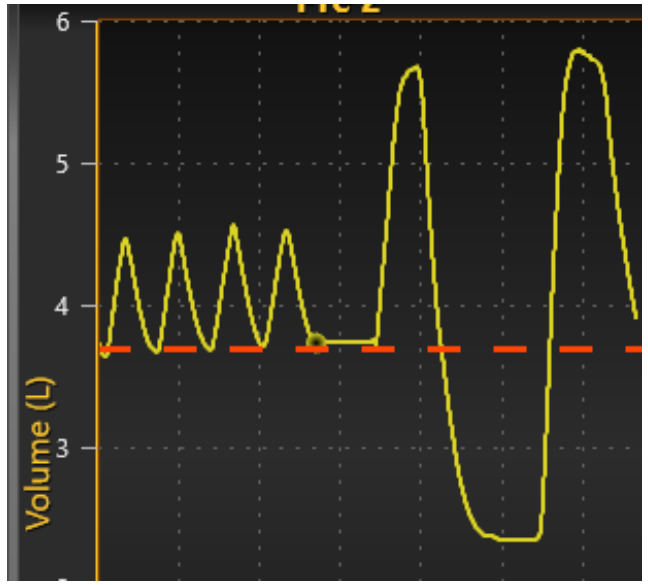


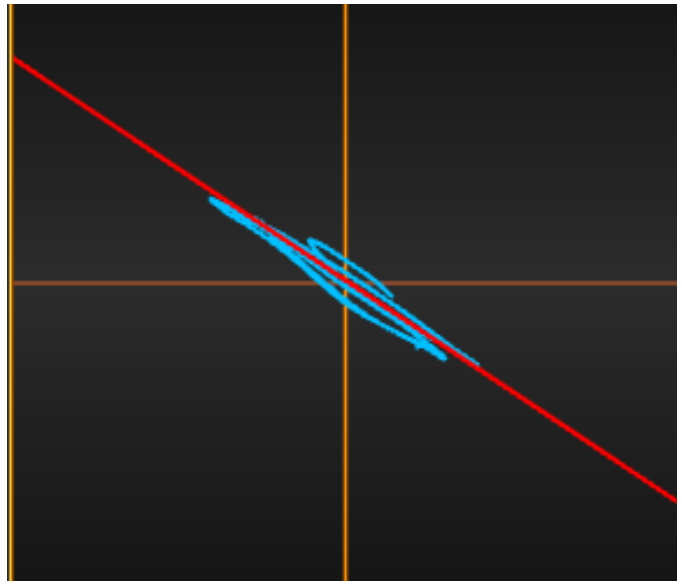
Example of Shutter Not Closed at FRC



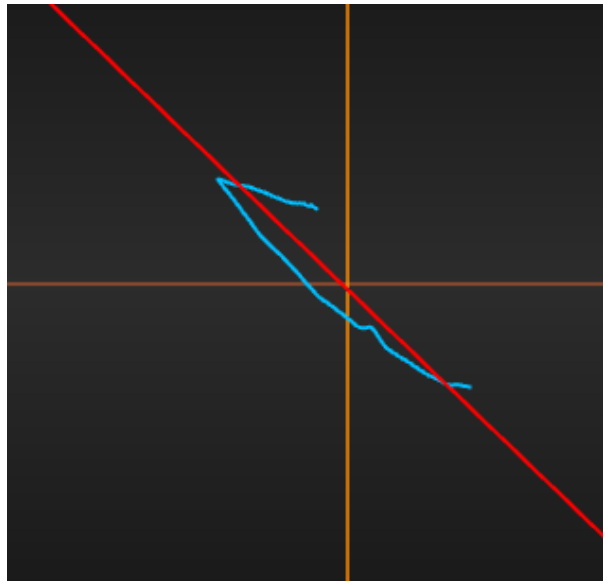


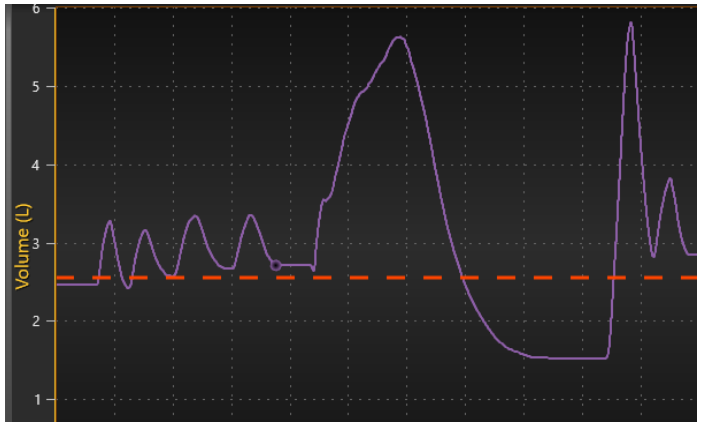






“Pant” Frequency Too Fast

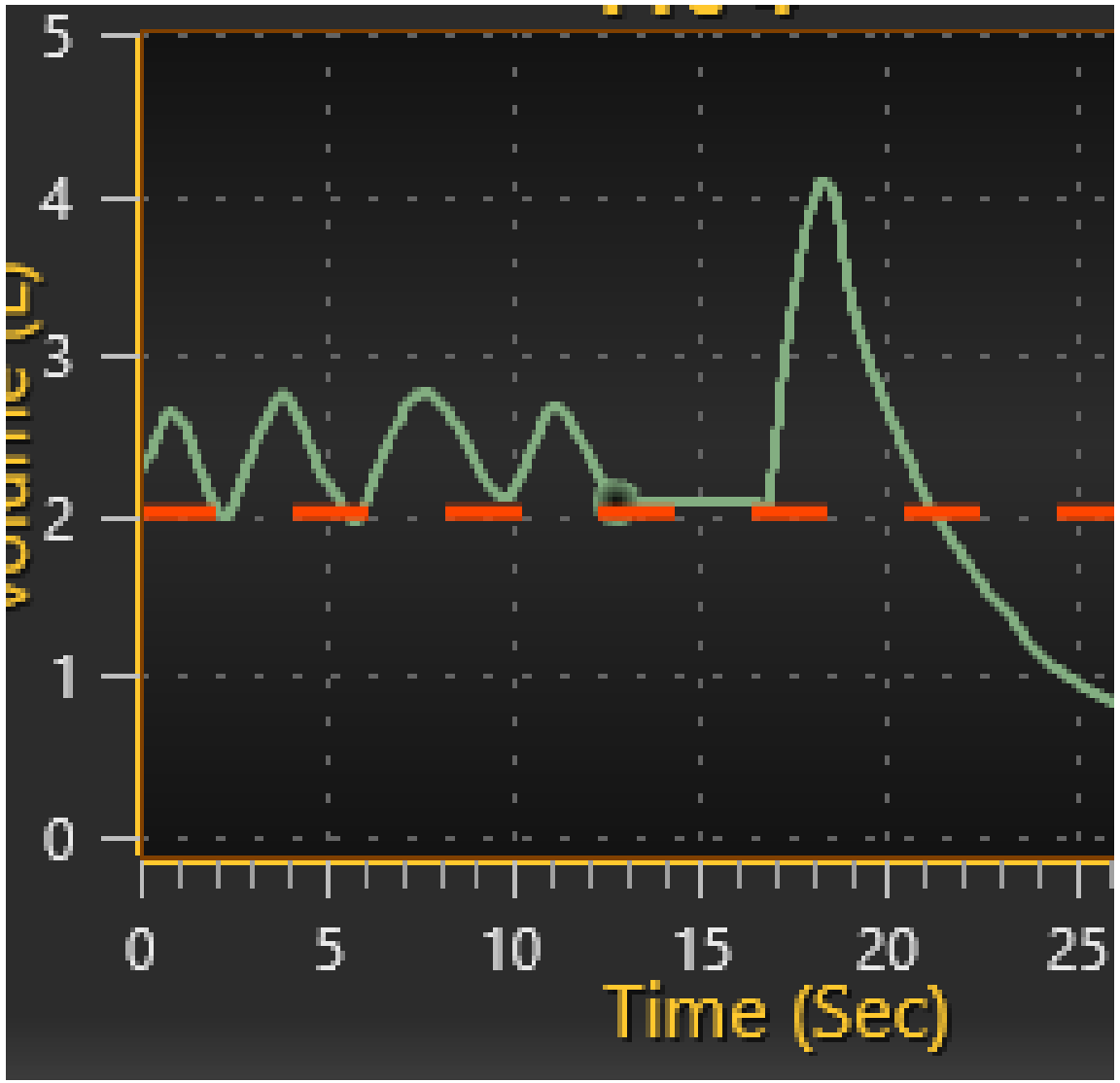




“Pant” Frequency Too Slow

Immediately After Shutter Opens…

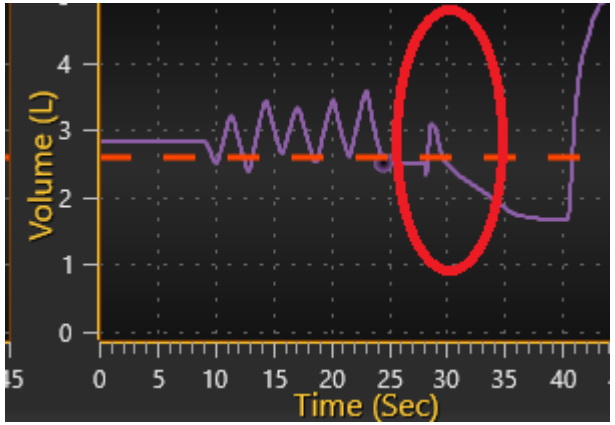
- Obtain a full IVC (inspiratory vital capacity)
  - Look at the patient to verify maximal inspiratory effort is given
- Coach patient to RV with a slow expiratory VC (vital capacity)
  - Important to do slowly or you can measure an overestimation of RV with a forced maneuver
  - Needs to be one continuous effort



Look For Acceptable Measurements

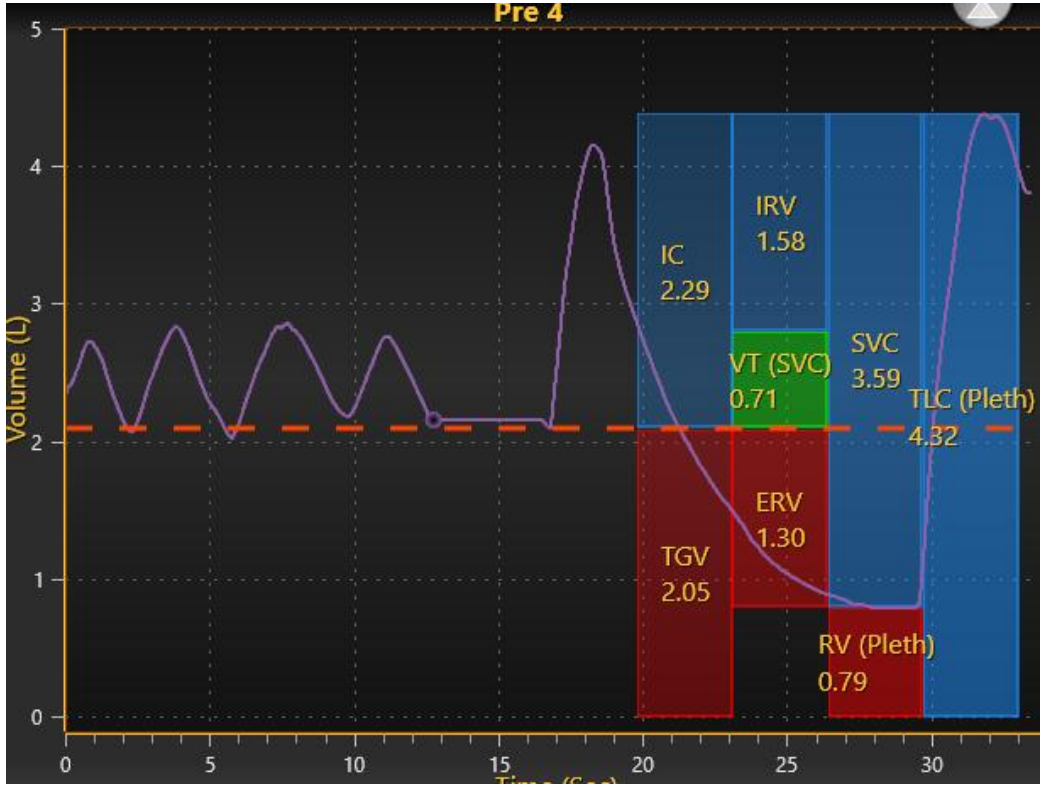
- Ensure a full IVC is obtained before the SVC maneuver

Verify that measurements are obtained from one continuous breath in, followed by one continuous exhalation



After RV is obtained and the patient can tolerate, coach them to a full IVC again.

- It’s good practice to obtain a second IVC to ensure the largest TLC is measured.



2023 Acceptability Criteria

Pre-shutter closure

- Breathing is stable (≥ 3 breaths)
- Panting occurs at end-tidal lung volume

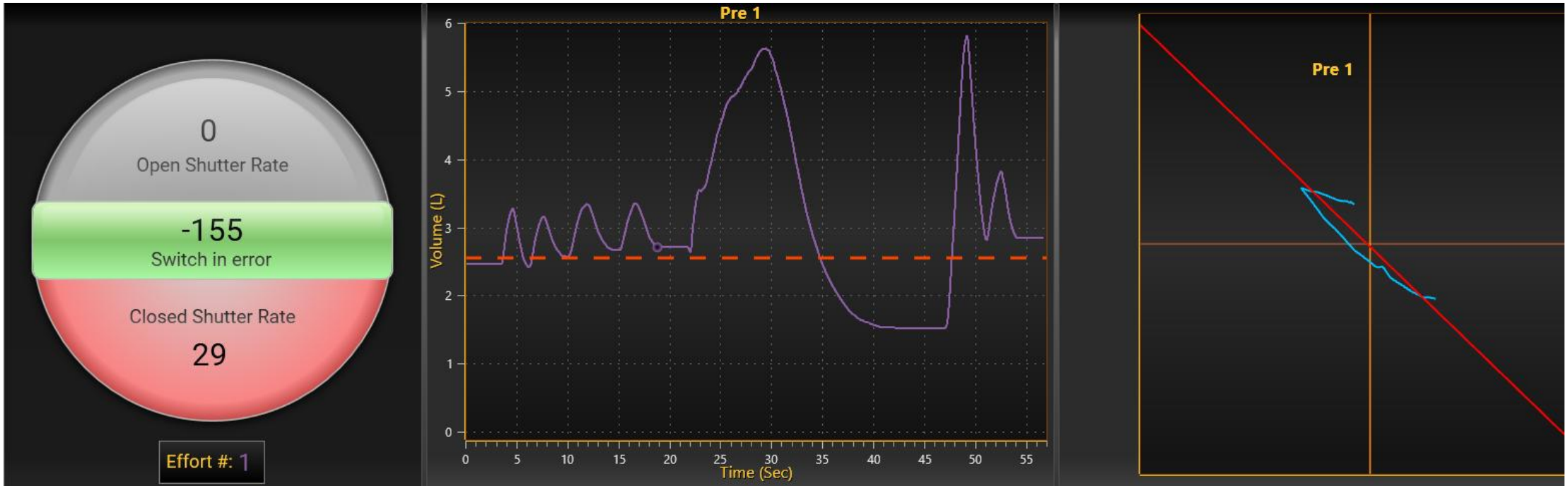
During shutter closure

- Closed loops
- Overlapping straight lines without thermal drift
- Pant frequency 0.5-1.0 Hz (30-60 bpm)

3 acceptable TGV(pleth) values that agree within 5% of the mean

(or 10% for FRC measurements)

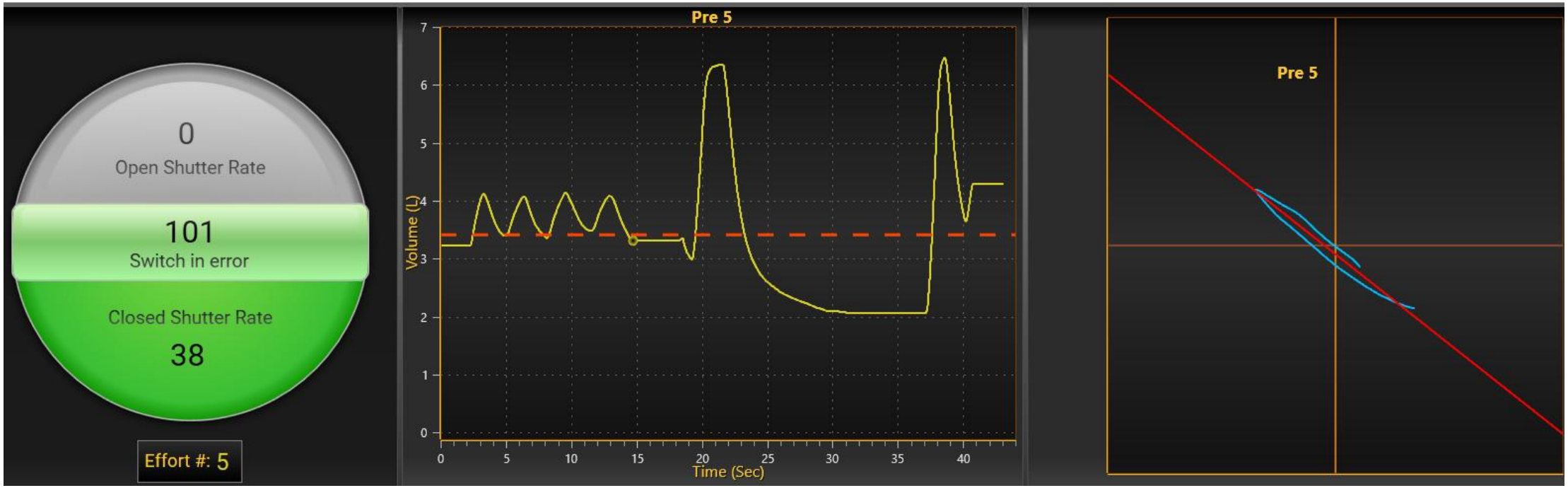
Acceptable?


0
Open Shutter Rate
-155
Switch in error
Closed Shutter Rate
29
Effort #: 1
Pre 1
Volume (L)
Time (Sec)
Pre 1

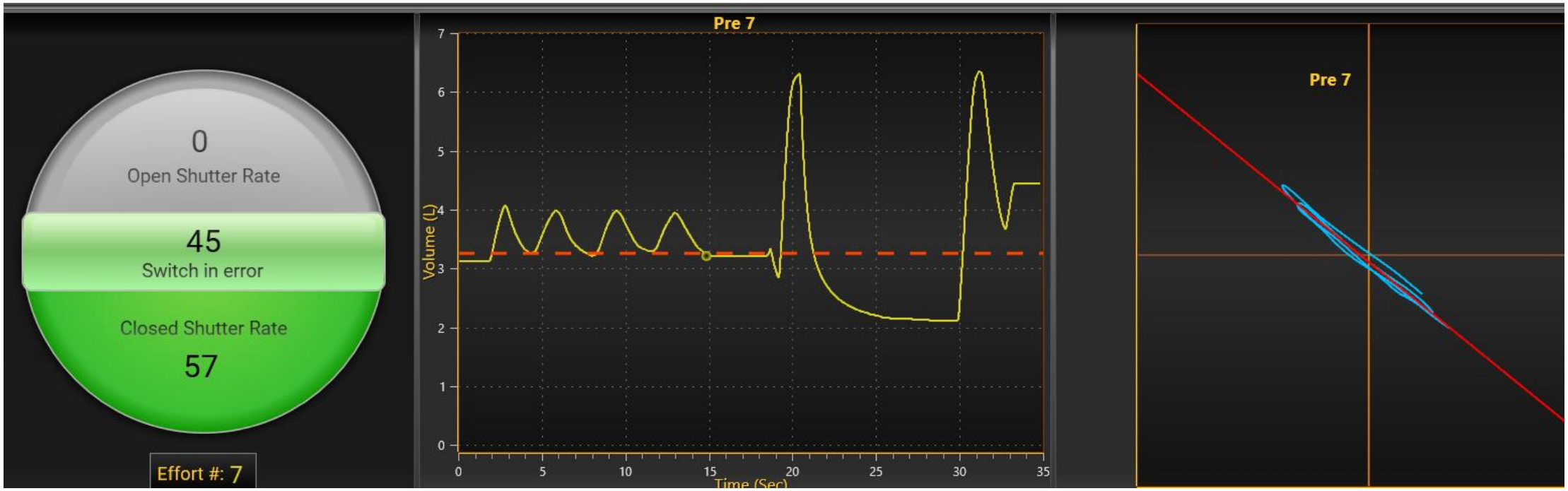
Acceptable?


0
Open Shutter Rate
-156
Switch in error
Closed Shutter Rate
0
Effort #: 2
Pre 2
Volume (L)
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40
45

Acceptable?


0
Open Shutter Rate
101
Switch in error
Closed Shutter Rate
38
Effort #: 5
Pre 5
Volume (L)
Time (Sec)
Pre 5

Acceptable?


0
Open Shutter Rate
45
Switch in error
Closed Shutter Rate
57
Effort #: 7
Pre 7
Volume (L)
Time (Sec)
Pre 7

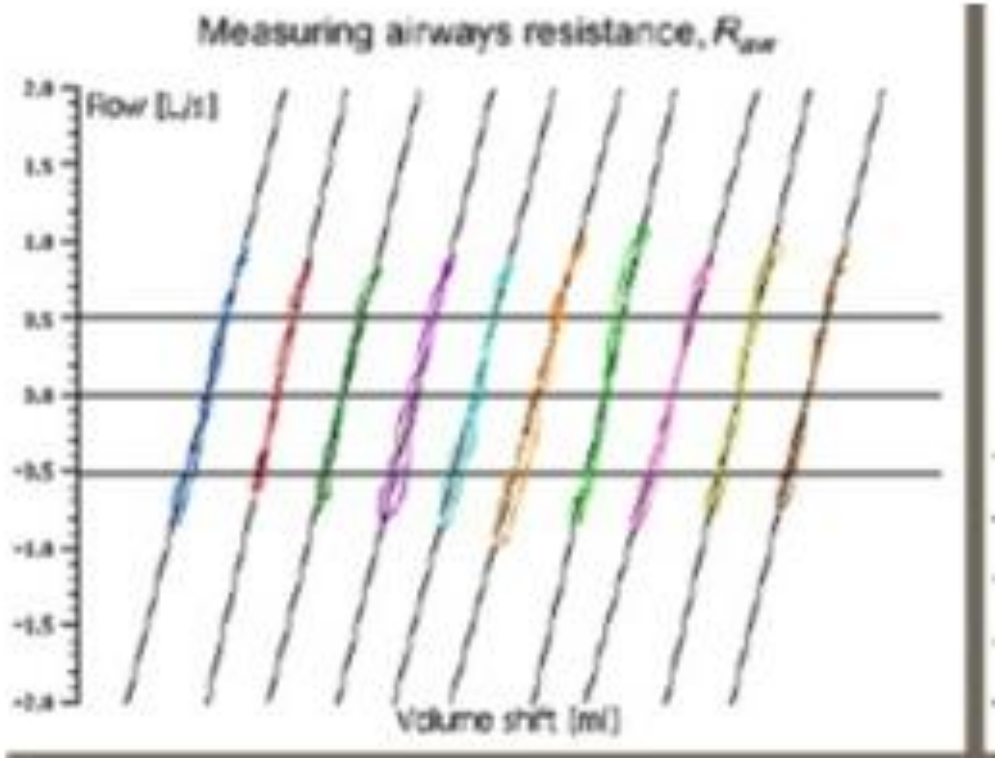
Repeatable?

	ULN	Pred	LLN	Pre	Best	%Pred	1	2	3	4	5	6	7	Z Score
Time							09:20:48	09:21:53	09:22:54	09:24:08	09:24:49	09:25:39	09:26:35	
RAW Sel							☐	☐	☐	☐	☐	☐	☐	
TGV Sel							☐	☐	☐	☐	✓	✓	✓	
Report Graph							☐	☐	☐	☐	☐	☐	☐	
TGV	3.88	3.02	2.16		3.31	109	2.55		3.60	3.07	3.41	3.26	3.26	
ERV	3.09	1.13			1.35	119	1.03	1.04	1.22	1.15	1.35	1.23	1.15	
RV (Pleth)	2.59	1.96	1.34		2.07	105	1.52		2.38	1.92	2.06	2.03	2.11	
SVC	10.64	3.40			4.40	129	4.28	4.25	4.20	4.21	4.40	4.30	4.24	
IC	7.45	2.27			3.05	134	3.25	3.22	2.98	3.05	3.05	3.08	3.09	
TLC (Pleth)	6.24	5.35	4.47		6.38	119	5.81		6.57	6.12	6.46	6.34	6.35	
RV/TLC (Pleth)	46	37	28		32		26		36	31	32	32	33	
Raw														
Open Freq														
Closed Freq					47		29		61	55	38	44	57	

	ULN	Pred	LLN	Pre	Best	%Pred	1	2	3	4	5	6	7
Time							09:20:48	09:21:53	09:22:54	09:24:08	09:24:49	09:25:39	09:26:35
Selected							☐	☐	☐	☐	✓	☐	☐
Report Graph							☐	☐	☐	☐	✓	☐	☐
Source							Pleth	Pleth	Pleth	Pleth	Pleth	Pleth	Pleth
SVC	4.31	3.40	2.51		4.40	129	4.28	4.25	4.20	4.21	4.40	4.30	4.24
IC		2.27			3.05	134	3.25	3.22	2.98	3.05	3.05	3.08	3.09
ERV		1.13			1.35	119	1.03	1.04	1.22	1.15	1.35	1.23	1.15

Airways Resistance

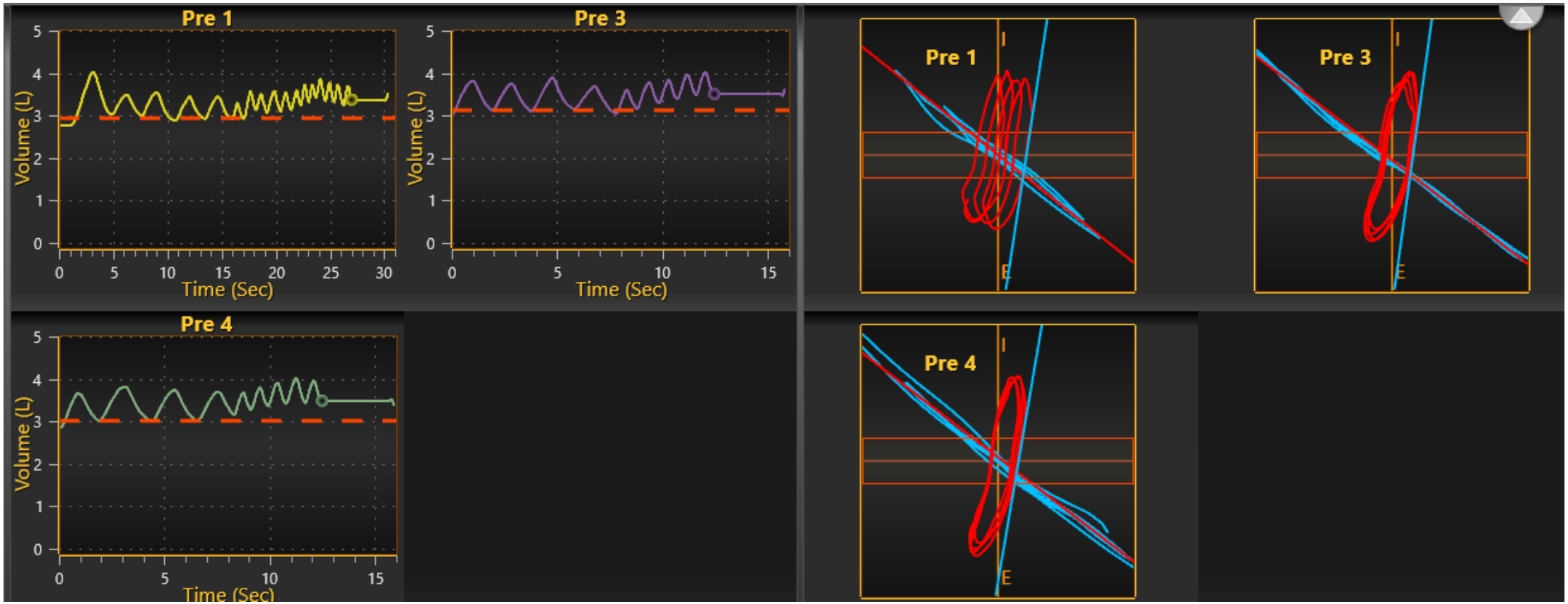
- The relationship between alveolar pressure and flow during open shutter breathing
- Raw = (Pm-Palv) / flow at the mouth
- Not commonly believed to be sensitive enough for clinical relevance

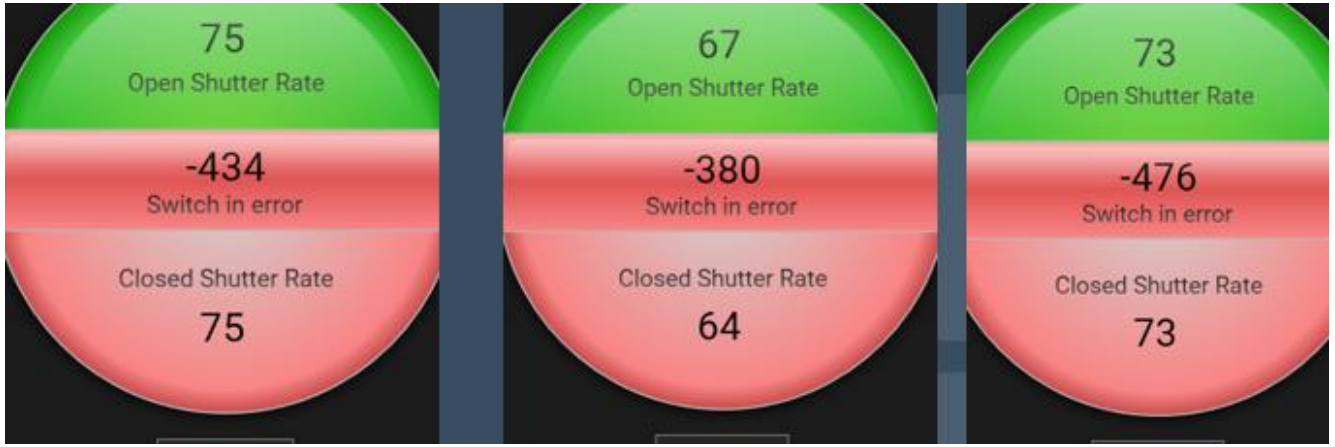


Obtain Airways Resistance As A Separate Maneuver

- *“Raw and its associated TGV must be measured independently of the lung volumes TGV manoeuver to ensure accuracy of lung volumes and airway resistance because the optimal panting frequencies are different and increased time on the mouthpiece increases opportunity for leak which can compromise accurate measurement of lung volumes. In addition, some patients may not tolerate the extended time on the mouthpiece and with the door closed when measurement of lung volumes and Raw are combined.”*

- https://erj.ersjournals.com/content/erj/early/2023/07/20/13993003.01519-2022.full.pdf


Pre 1
Volume (L)
Time (Sec)
Pre 3
Volume (L)
Time (Sec)
Pre 4
Volume (L)
Time (Sec)
Pre 1
I
E
Pre 3
I
E
Pre 4
I
E


75
Open Shutter Rate
-434
Switch in error
Closed Shutter Rate
75
67
Open Shutter Rate
-380
Switch in error
Closed Shutter Rate
64
73
Open Shutter Rate
-476
Switch in error
Closed Shutter Rate
73

Quality Control

- Mouth pressure transducer and pleth signal should be calibrated daily or prior to use
  - Calibrate twice a day when temperature or barometric pressure are changing

Quality Control

- Isothermal lung model validation must be performed monthly, when new software is uploaded, or a problem suspected
  - This simulates isothermal conditions within the lung, use care when editing the settings during this maneuver

Isothermal Bottle Training

Quality Control

- At least monthly, or when errors are suspected, 2 healthy non-smoking biologic controls should be tested with coefficients of variation < 5% for both FRC and TLC.
- CV data are available in PFT software to review operator data.