# Plethysmography Test Performance
# Raw and Lung Volumes
# A Review

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# Lung Volume by Plethysmography Clinical Indications

- The measurement of TLC to distinguish between restrictive and obstructive processes.
- The evaluation of the pathophysiology of obstructive lung diseases that may produce artifactual results when measured by dilution methods.
- Measurements requiring repeated trials.

# Airway Resistance Clinical Indications

- Bronchodilator response
- Bronchial provocation testing
- Pre- and post- surgical intervention for UAO

# Plethysmography Terminology

- Thoracic Gas Volume (TGV) – also known as $V_{pant}$
  - A non-specific term. Volume of air in thorax at time shutter closure.
    - Measured during lung volume measurements to obtain $FRC_{pleth}$
    - Measured at the end of airway resistance measurements to correct the resistance measurement to the lung volume at which it was measured

# Plethysmography Terminology

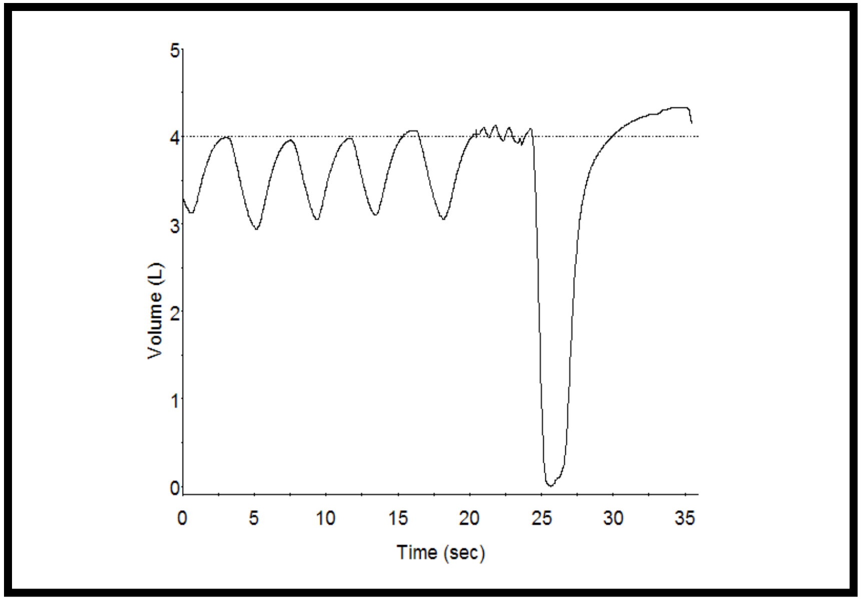
- Functional Residual Capacity ($FRC_{pleth}$)
  - Volume of air contained within the thoracic cage measured by plethysmography and corrected to the average end-expiratory lung volume that preceded the shutter closure that measured TGV

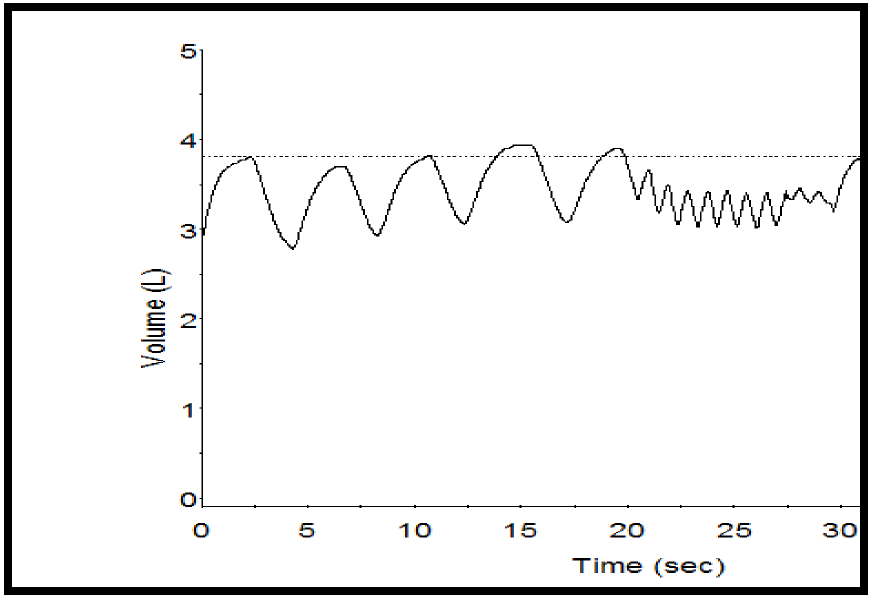
# Airway resistance and lung volume

- $sR_{aw}$
  - $sR_{aw} = R_{aw} \times V_{pant}$
  - Inverse, linear relationship to lung volume

- $sG_{aw}$ ($G_{aw}$ relative to measured lung volume)
  - $sG_{aw} = 1/sR_{aw}$ or $1/(R_{aw} \times V_{pant})$
  - $sG_{aw}$ is not volume-dependent; can be used to assess change in airway resistance even if lung volume changes.

# TGV ($V_{pant}$ )




**Shutter closure at end-expiration**

**Shutter closure during panting**

# Plethysmography Measurements

- Lung volumes requires stable resting EELV
  - Shutter closed after stable EELV established, then:
    - FRC to RV to TLC (preferred) *or*
    - FRC to TLC to RV

- Rapid panting of Raw raises EELV
  - Shutter closed at end of collection to measure TGV for correcting Raw to sGaw

# Considerations Prior to Testing

- Calibration

- Quality Aspects
  - Test Performance
    - Instrument
    - Patient

  - Test Review

  - Error Recognition

  - Troubleshooting

  - Data Reduction

# Calibration

- Environmental parameters MUST be checked for accuracy including barometric pressure, temperature, and box volume.

- Devices to calibrate daily:
  - Flow Sensor
  - Mouth pressure Transducer
  - Box pressure Transducer
  - Box leak test (time constant)

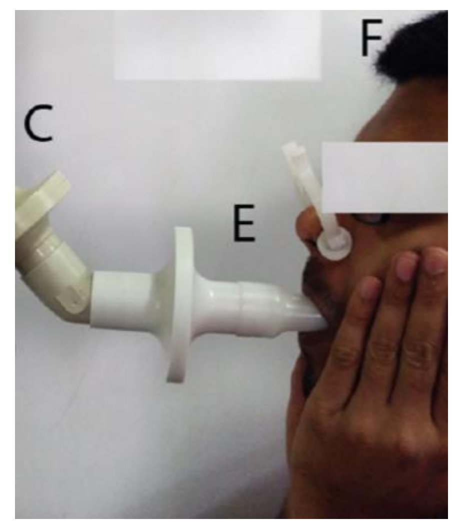
# Cheek support

- Changes in mouth pressure and box pressure are the primary signals in closed shutter maneuver

- During expiratory phase, the cheeks can bow outwards if not supported
  - Mouth pressure signal diminished
  - Can produce unusable TGV loops

- ATS says ‘support with fingertips’

  but flat of palm works better



# Mouthpiece

- Whenever possible, dentures remain
- Rigid round or oval filter mouthpiece works for some, not all patients
- Flanged mouthpiece helps maintain air-tight seal during closed shutter maneuver

# Pre-test

- Smoking, eating and physical activity
  - Avoid for 1 hour
- Discontinue IV*
- Discontinue supplemental oxygen*
- Withhold bronchodilators*

# Pre-test

- Open-door phase
- Closed door phase
- Performance criteria
- Coaching/reassurance
- Performance assessment
- Data selection/reporting

# Patient Management
# Reassurance

- Reassure the patient to relieve anxiety associated with the test or sitting within the cabinet
- The test will take 3-4 minutes
- The door can be released at any time from the inside (manufacturer-specific)

# Patient Management Explanation

- Open-door phase
  - Thoroughly explain the procedure
    - Open shutter-”like a small piston”
    - Closed shutter- brief, gentle efforts
      - ‘try panting with your hand over your mouth’
    - Cheeks **must** be supported by hands
  - Demonstrate the maneuver
  - Practice with the patient
  - Emphasize relaxing and breathing normally between measurements

- Door Closed Phase
  - Practice while waiting for thermal stability
    - 30-45s minimum

# Patient Management
# Closed Shutter Explanation

- Patient performance criteria
  - Emphasize consistent, brief, gentle efforts between 0.5-1.0 efforts/sec (30 to 60/minute)
  - Relax between efforts
    - ‘pull’ – pause – ‘push’ – pause – ‘pull’ – pause – ‘push’
    - ‘in’ – pause – ‘out’ – pause – ‘in’ – pause – ‘out’

  - Emphasize this is NOT an MVV or MIP/MEP
  - Provide continuous feedback on performance

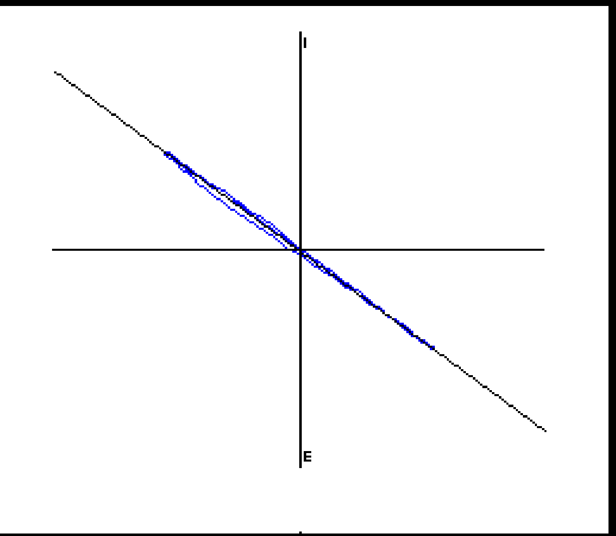
# Patient Management Coaching

- Provide Real time feedback
- Practice Maneuver Prior Door Closure
- Practice Maneuver After Door Closure
- Evaluate and Correct during Testing

# Test Procedure Preparation

- Instrument warmed up, then calibrated
- LEAVE THE DENTURES IN! (unless they interfere)
- Seat in box – proceed to open door phase
  - Get patient to relax – talk to them
  - Explain procedure; practice pant with hand over mouth
  - Adjust mouthpiece height, shouldn't be too low or high
  - Practice mouthpiece and nose clip placement
  - Practice cheek support
- Close door – wait for thermal equilibration (30-60s)

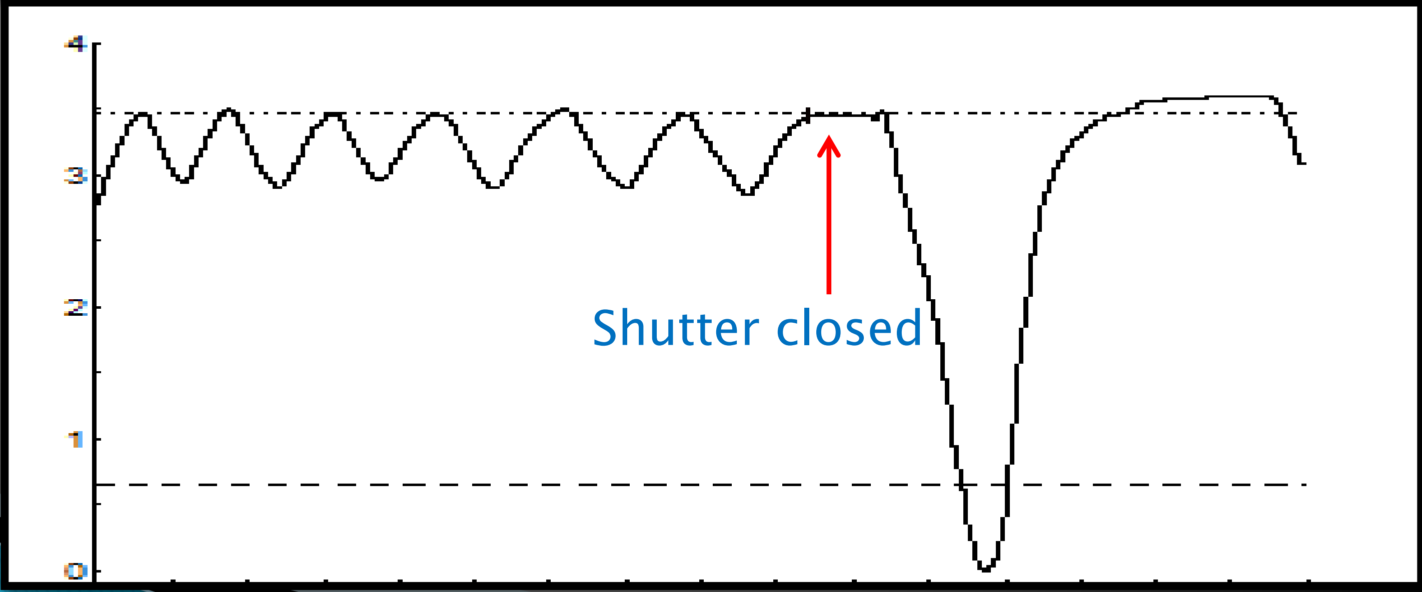
# 3 Phases of Lung Volume by Plethysmography Measurement




1. **Establish FRC - resting tidal breathing, establish stable baseline (EELV) for 3-10 Breaths.**

2. **Measure TGV - close shutter at end-expiratory lung volume; brief, gentle pant efforts for 2-3 s**

3. **Measure VC - open Shutter, exhale to RV then inhale to TLC or inhale to TLC and exhale to RV (minimal effort).**



# Metronome vs. Coaching Cadence during closed shutter

- Shutter typically closed for 2-3s
- Any coaching of cadence (including metronome) before shutter will typically increase respiratory rate
- Increasing respiratory rate when obstruction is present will increase EELV
- Control cadence only <u>after</u> shutter closes

# After first lung volume measurement…

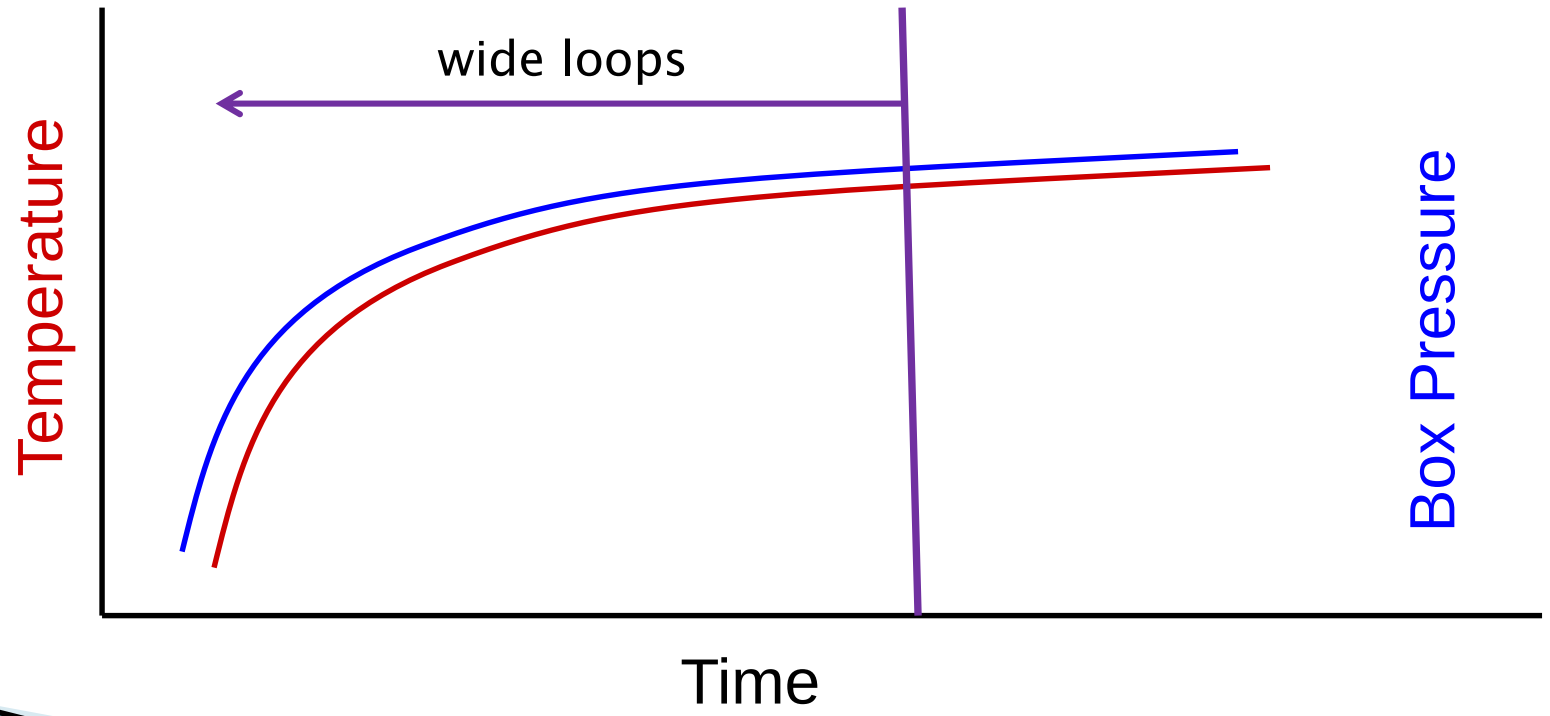
- Often good to allow patient to remove noseclips and come off mouthpiece to rest
  - Opening door can reduce stress, allow nasal $O_2$
- Talk to/assess patient
- Review results
  - Look at stability of EELV prior to shutter
    - Assess line of best fit of 3-5 breaths; adjust if needed
  - Examine TGV loop
    - too small, too large, unidirectional, slope correct?
- Reinstruct and resume – goal is 3-5 repeatable, linked LVs

# Lung Volume by Plethysmography Common Errors

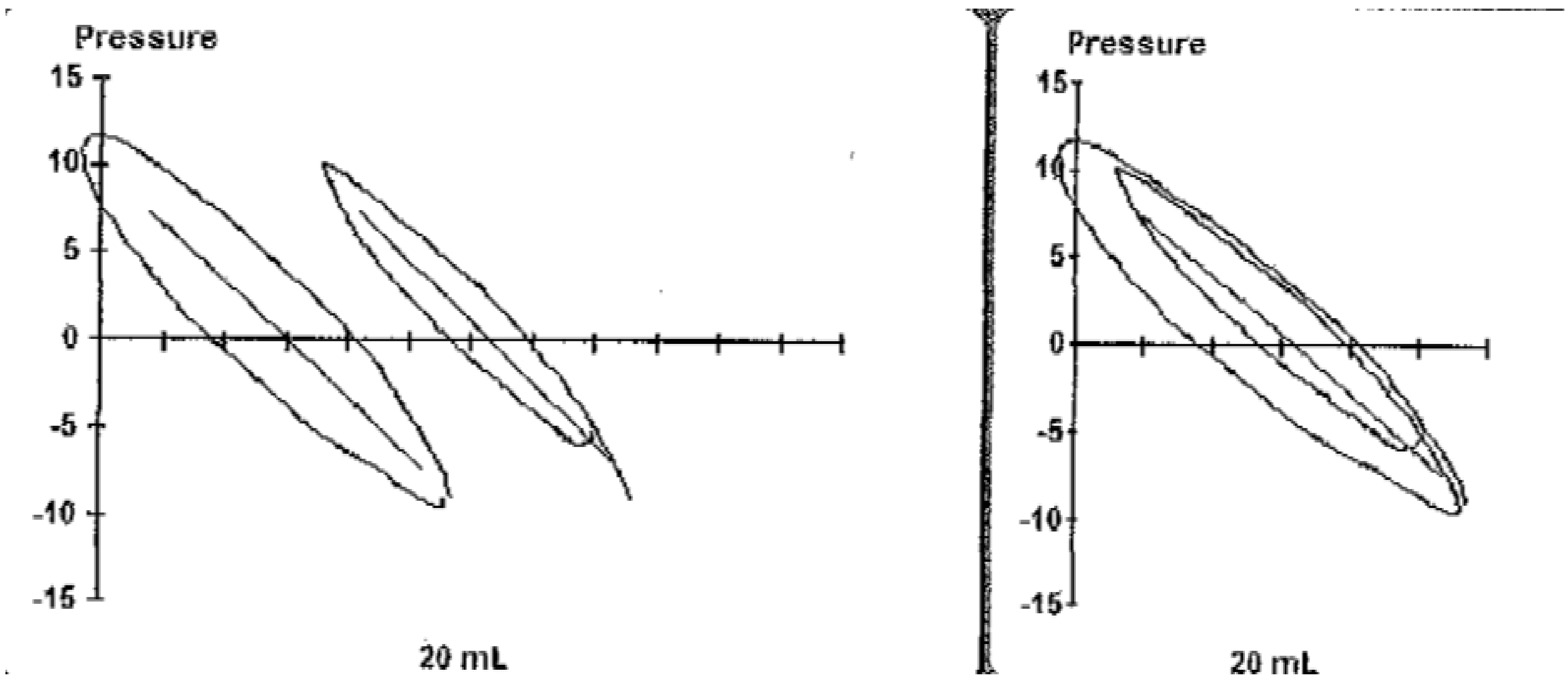
- Starting the measurement before thermal equilibration achieved
- No stable resting end-expiratory lung volume (EELV) during tidal breathing
- Pant effort unidirectional
- Pant frequency too fast
- Pant frequency too slow
- Pant effort too large
- Pant effort too small
- Glottis closing during effort
- Improper vital capacity maneuver after shutter opens
- Unlinked lung volumes
- One shutter closure for both lung volumes and airway resistance

# Starting the measurement before thermal equilibration achieved

Typically 30–120s after door sealed



# Wide loops caused by starting measurement too soon same loop can result from panting too slowly



# Common Lung Volume Errors

## unstable resting EELV during tidal breathing

- Causes:
  - Anxiety
  - Dyspnea
  - Confusion
- Correction
  - Relaxed tone of voice
  - Guided imagery
  - Minimize time
  - Thorough explanation
  - Good coaching

# Common Lung Volume Errors

## Pant effort unidirectional

- Causes:
  - Poor understanding
  - Expectation of airflow
  - Loss of attention to coaching

- Correction
  - Thorough explanation
  - Practice
  - Good coaching

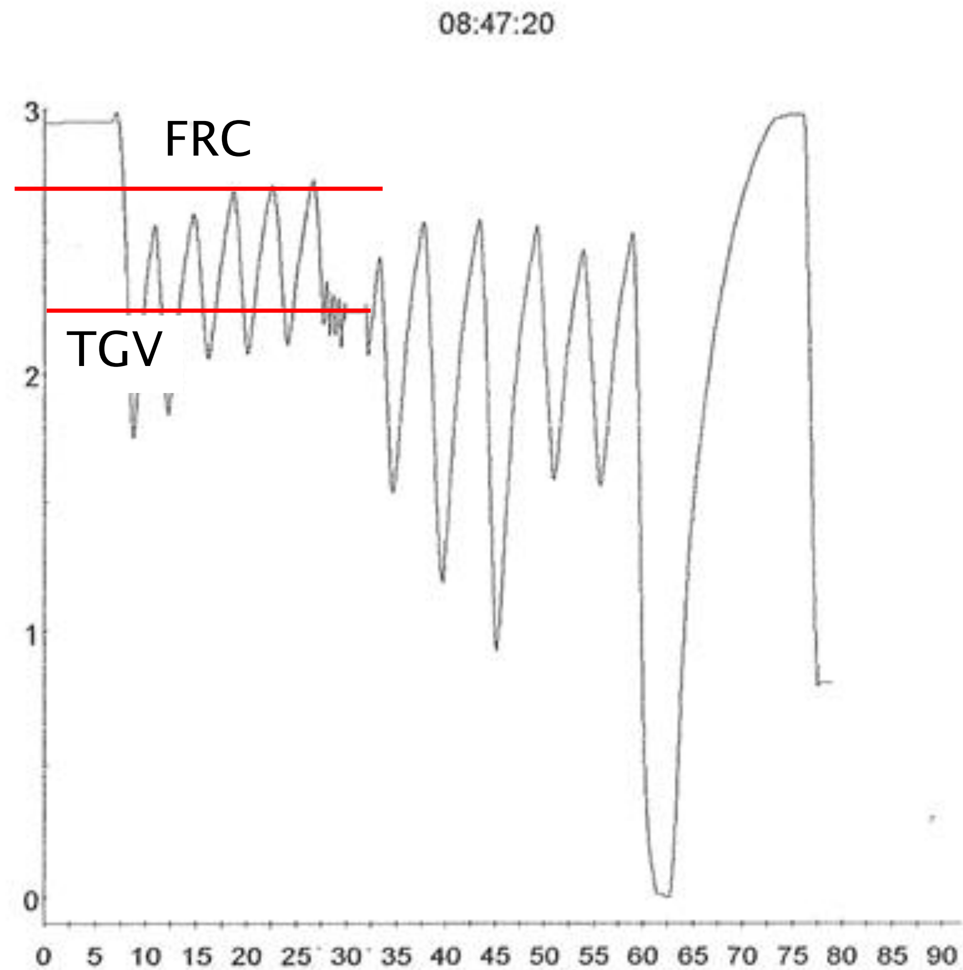
# Common Lung Volume Errors

## Pant frequency too fast

- The assumption that mouth pressure = alveolar pressure no longer valid at pant frequencies above 90/minute.
- Mouth pressure will underestimate alveolar pressure resulting in an overestimation of $FRC_{pleth}$.
  - Causes:
    - Improper coaching
    - Anxiety
    - Dyspnea
    - Confusion
    - Airway resistance measurement
  - Correction
    - Relaxed tone of voice
    - Thorough explanation
    - Practice hand over mouth with coaching of cadence

# Pant frequency too fast
## 0.5L increase in EELV before shutter

Try to keep tidal end-expiratory baseline and shutter volume within 200mL



# Common Lung Volume Errors

## Pant frequency too slow

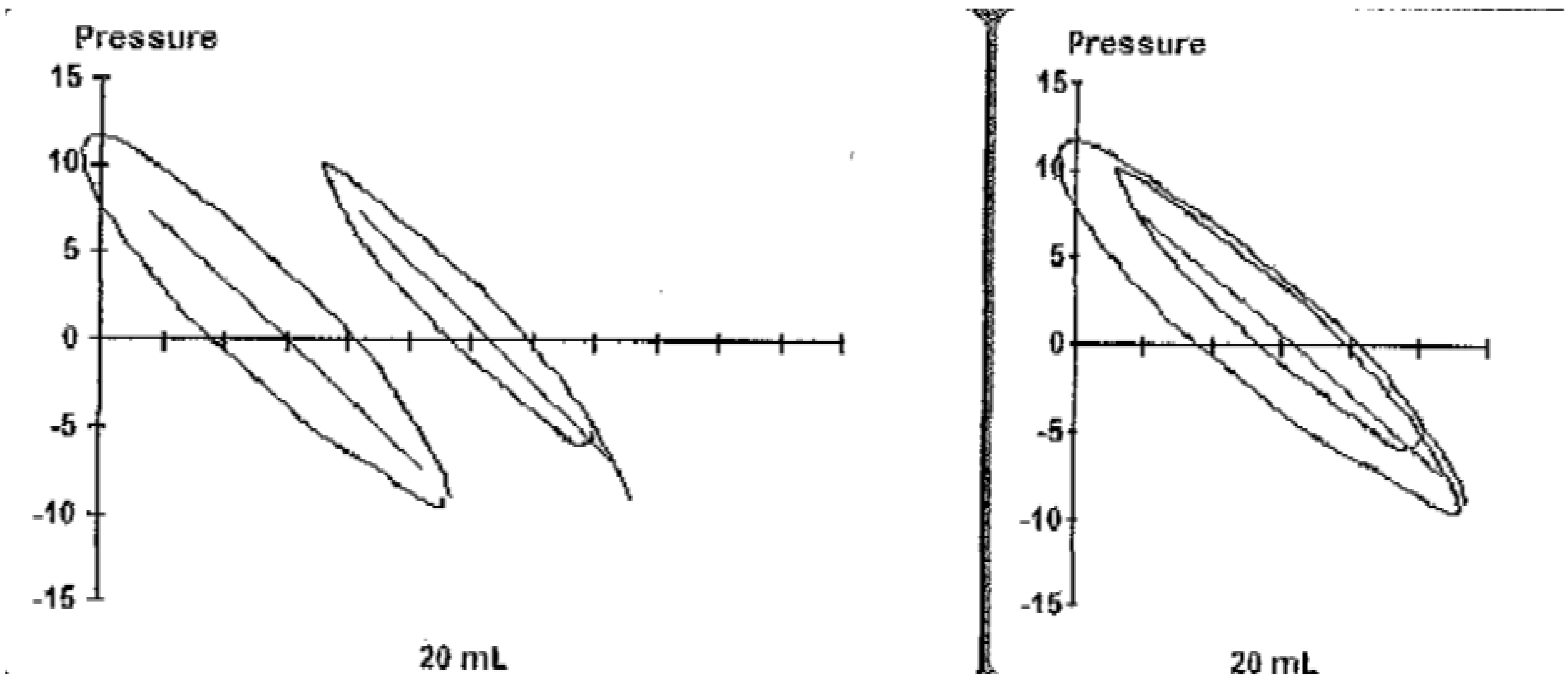
Thermal drift causes wider TGV loops making slope assignment more difficult

- Causes:
  - Failure to follow cadence
    - too slow (< 30/minute)
  - Confusion

- Correction
  - Relaxed tone of voice
  - Thorough explanation
  - Practice with coaching of cadence

# Wide loops caused by panting too slowly

## same loop can result from starting measurement too soon



# Common Lung Volume Errors

## Pant effort too small (<5cmH20 or 0.5kPa)

Difficult to assign TGV slope.

- Causes:
  - Confusion
  - Anxiety
  - Weakness

- Correction
  - Coaching at time of testing
  - Between-effort discussion

# Common Lung Volume Errors

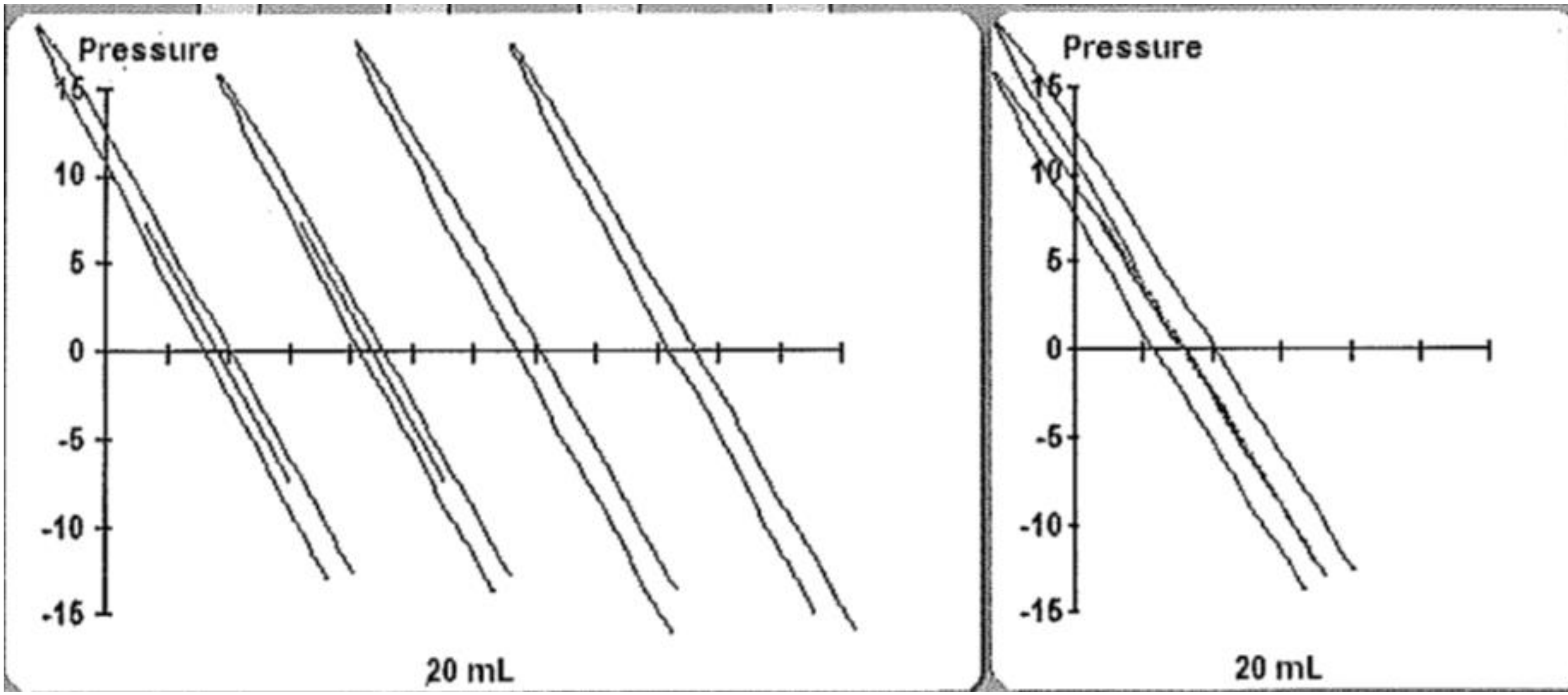
## Pant effort too large (>20cmH2O or 2kPa)

Difficult to assign TGV slope.

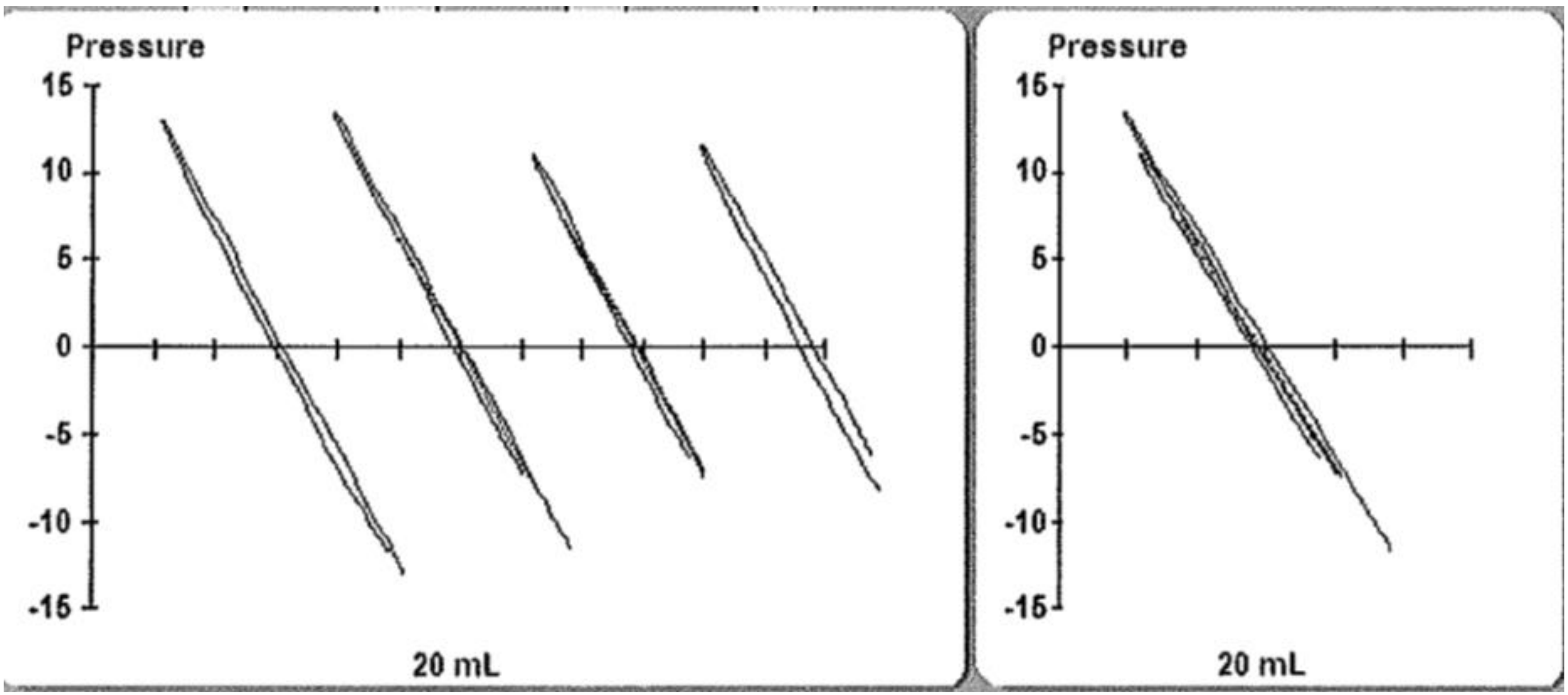
- Causes:
  - Confusion/poor understanding
  - Anxiety

- Correction
  - Coaching at time of testing
  - Between-effort discussion

# Pant effort too large



# Same patient after reinstructing



# Common Lung Volume Errors

## Improper Vital Capacity Maneuver

- Examples:
  - Unlinked to baseline and shutter maneuvers
  - Forcing the exhalation
  - Poor ERV maneuver (too short)
  - Poor IC maneuver (no plateau)

- Correction
  - Instruct and Coach
  - Demonstrate

# ‘Linked’ Lung Volumes

- Lung volume measurement – 3 phases
  - Stable EELV established
  - Lung volume at or near EELV measured
  - Vital capacity measured
    - ERV to TLC (ATS preferred) or IC to RV

- ‘Linked’ means 3 phase are tied to each other
  - (patient doesn’t come off mouthpiece until all 3 events have been completed)

# Patient Performance

## Lung Volume Acceptability Criteria

- Stable resting EELV (minimum of 3 breaths)
  - No evidence of leaks or drift
- Panting Frequency should be ~ 1.0 br/sec
  - 30-60/min - no higher than 90/min!
- Linear, appropriately sized loops
- 3-5 repeatable efforts
  - ($FRC_{pleth}$range/mean <5%)

# Editing Lung Volumes

- Delete (deactivate) unacceptable efforts
- Adjust lines representing EELV, if necessary
  - At least 3 breaths
  - Can ignore last breath if patient reacted to imminent shutter closing
- Adjust TLC and RV points
- Adjust slopes on TGV loops, if necessary
- Check FRC (and RV, TLC) variability

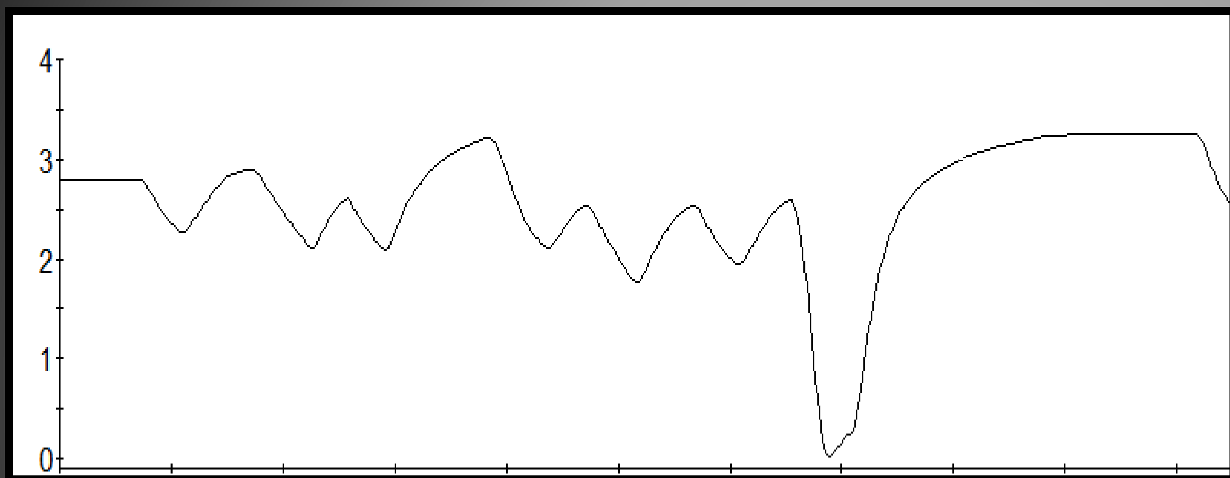
# Lung Volume Variability

- $\geq$ 3 acceptable FRCpleth within 5% of the mean

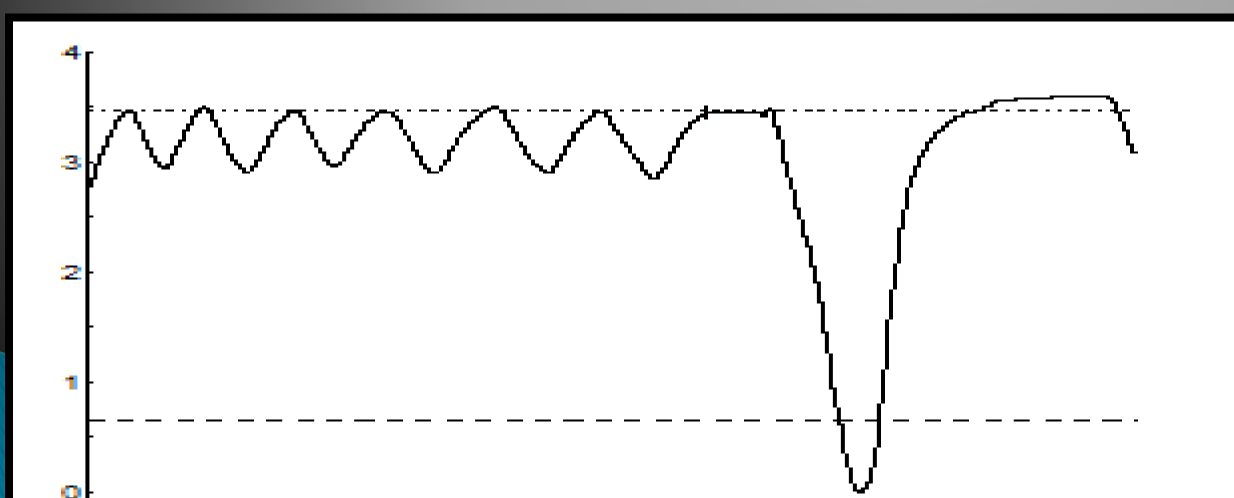
$$\frac{(\text{Largest } FRC_{pleth} - \text{smallest } FRC_{pleth})}{\text{mean } FRC_{pleth}} \leq 0.05$$

- Linked VCs show $\leq$ 0.15L variability

# Evaluating Tidal Breathing

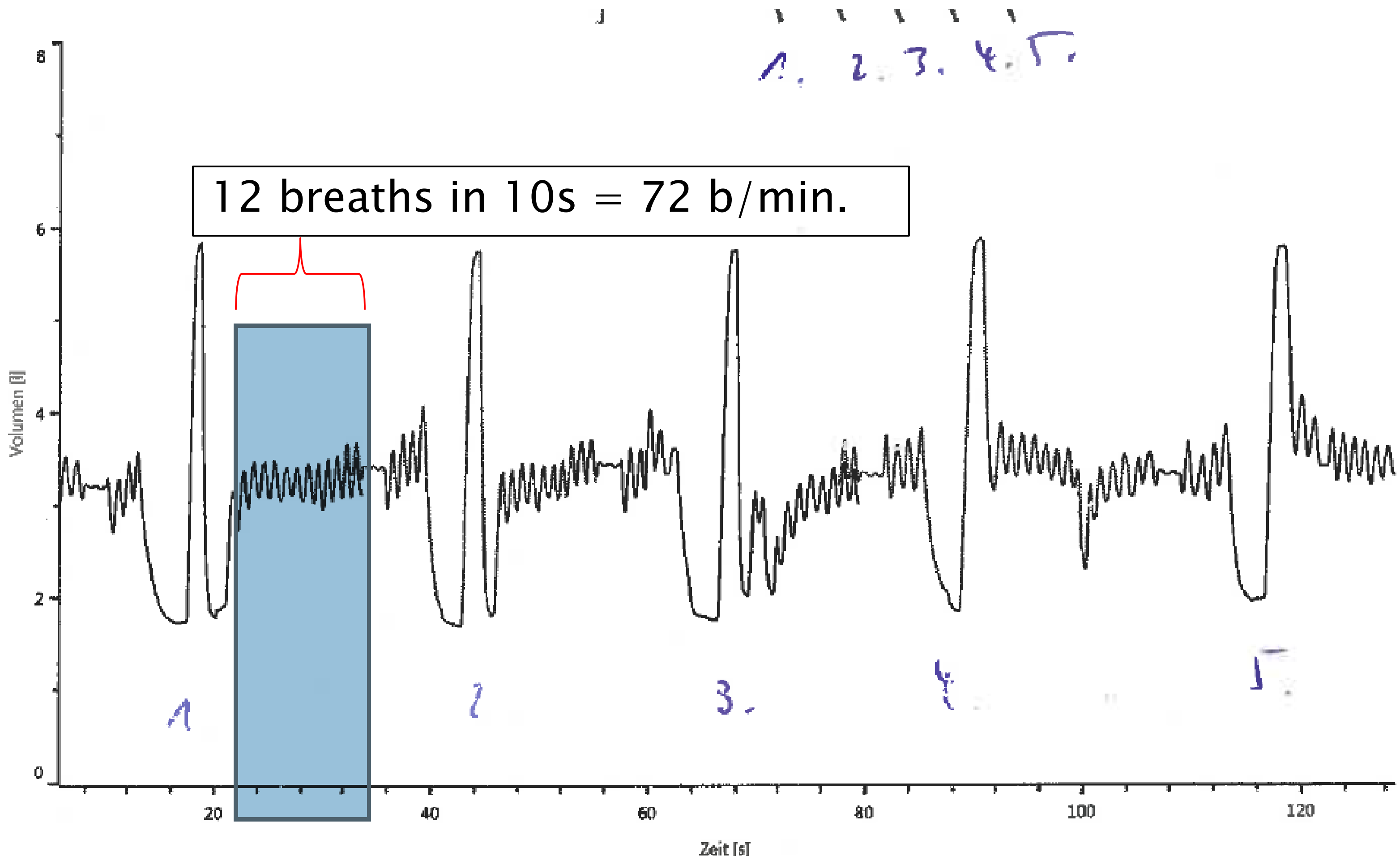



Unstable Tidal Breathing

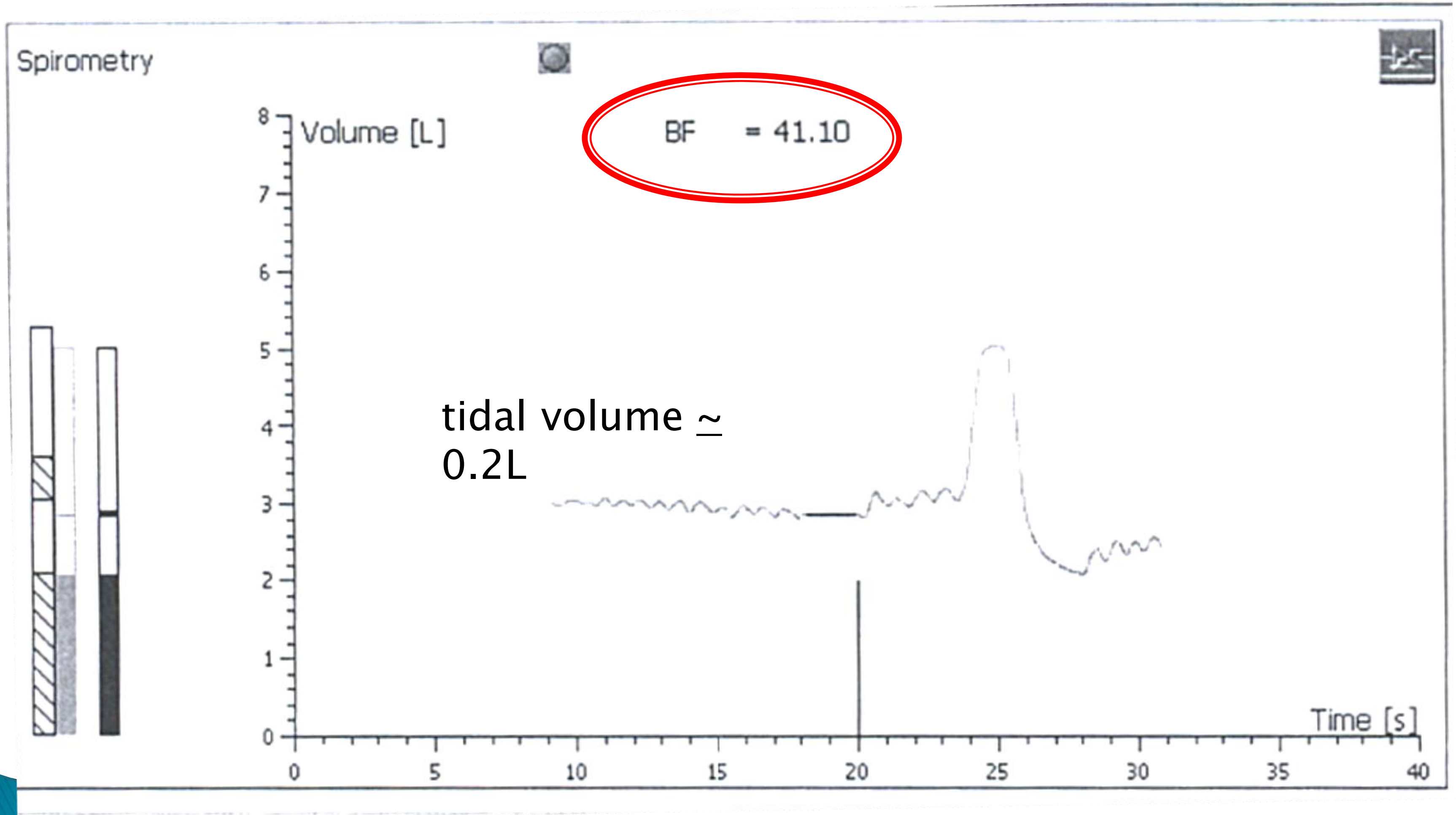



Stable Tidal Breathing

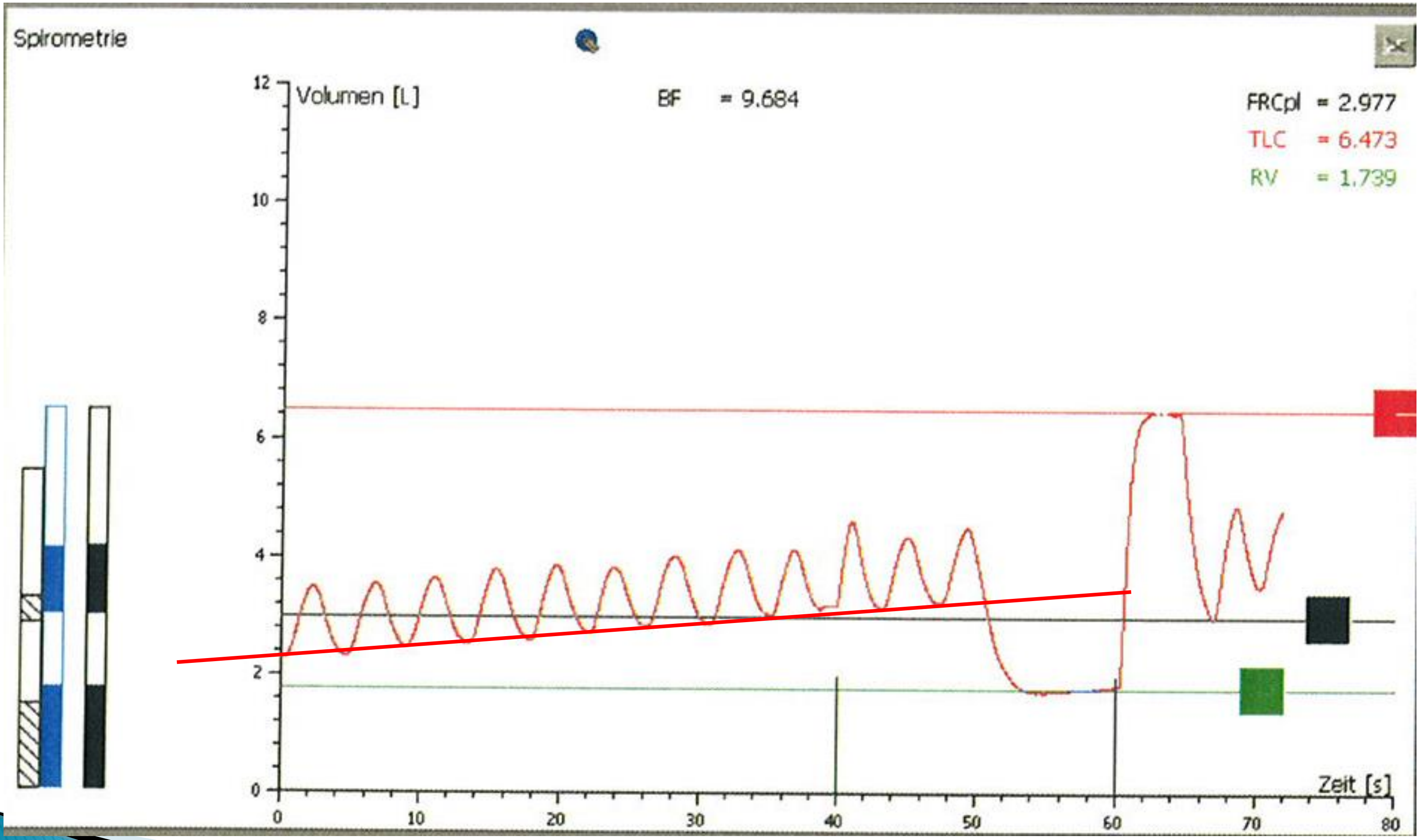
# Resting Tidal Breathing?



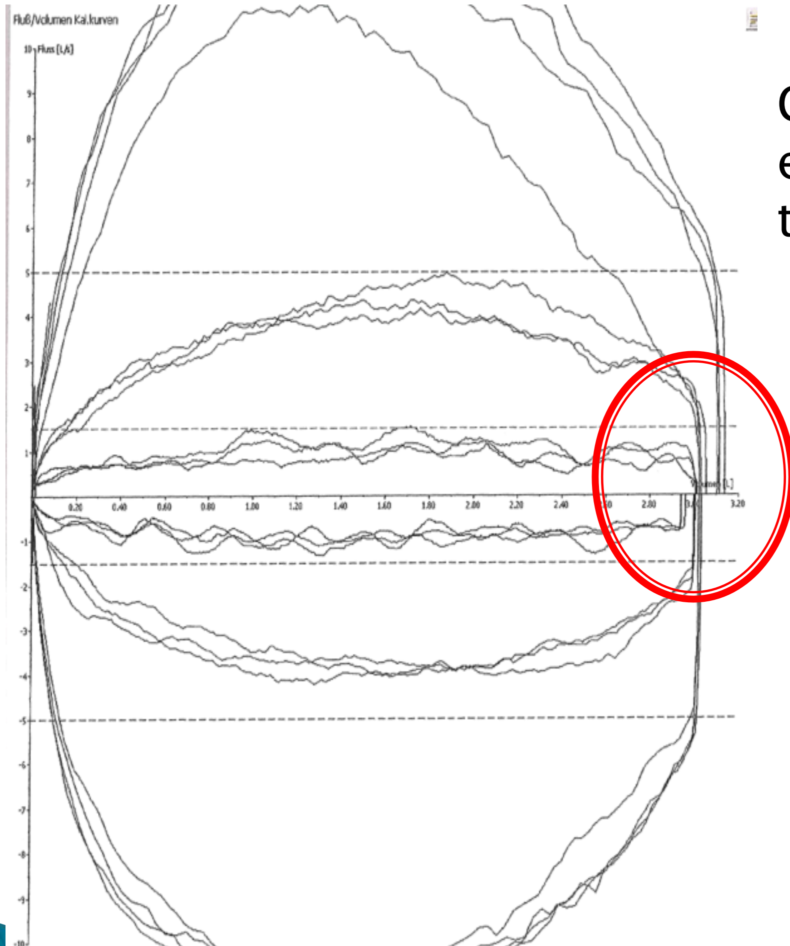
# Resting tidal breathing?
# VC = 87% of predicted



# Why is tidal EELV sloping upward?



# Calibrate/Verify using 3 flows Consider low-flow range agreement




Consider that Inspiratory and Expiratory errors are cumulative and sum with each tidal breath.

Example:
Low flow range expiratory error: -2%
Low flow range inspiratory error: +2%

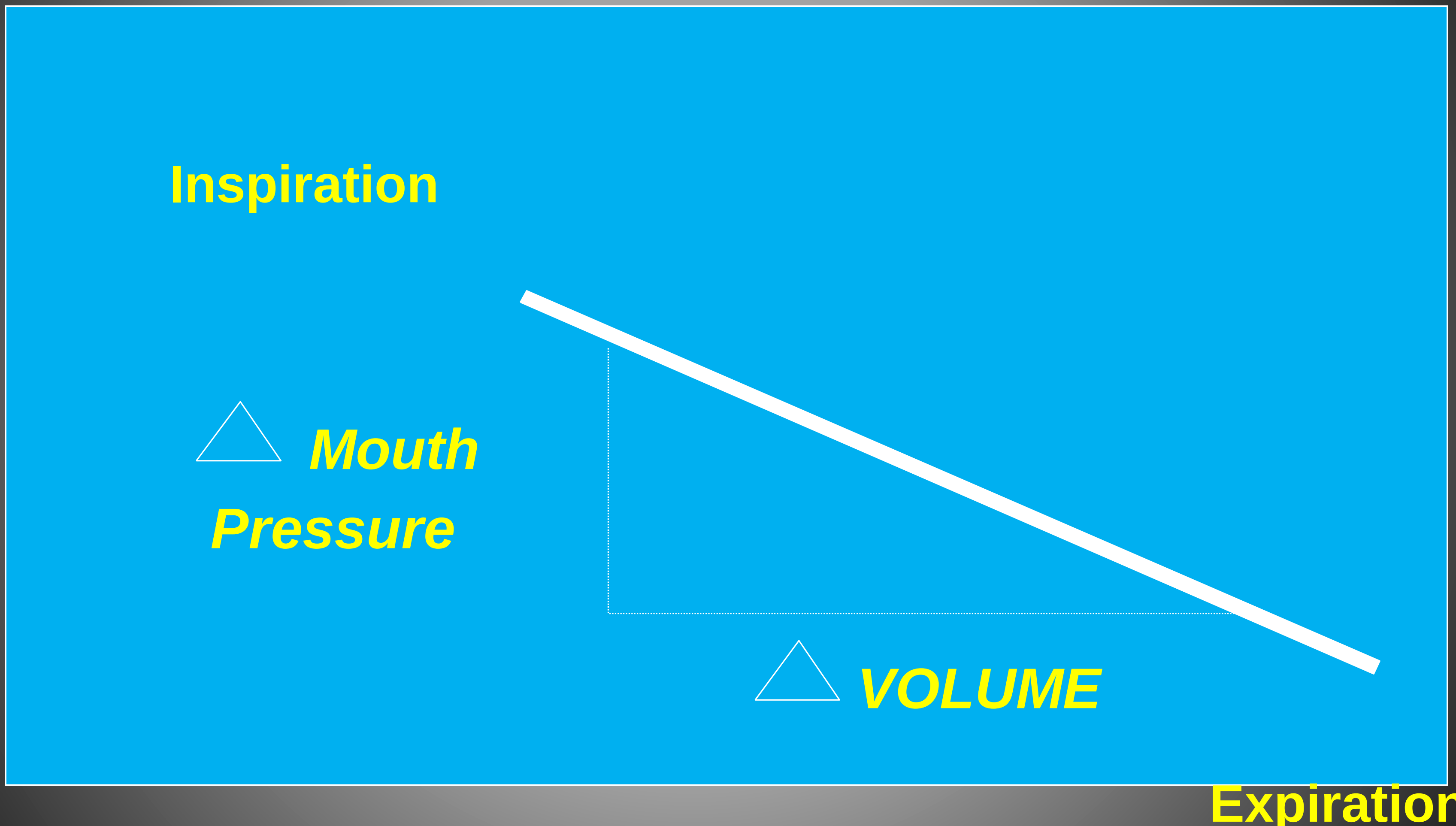
Each tidal breath will show 4% discrepancy in volume

*inspiratory volume ~ 4% larger than expiratory volume

# Reviewing the Acceptable Trials

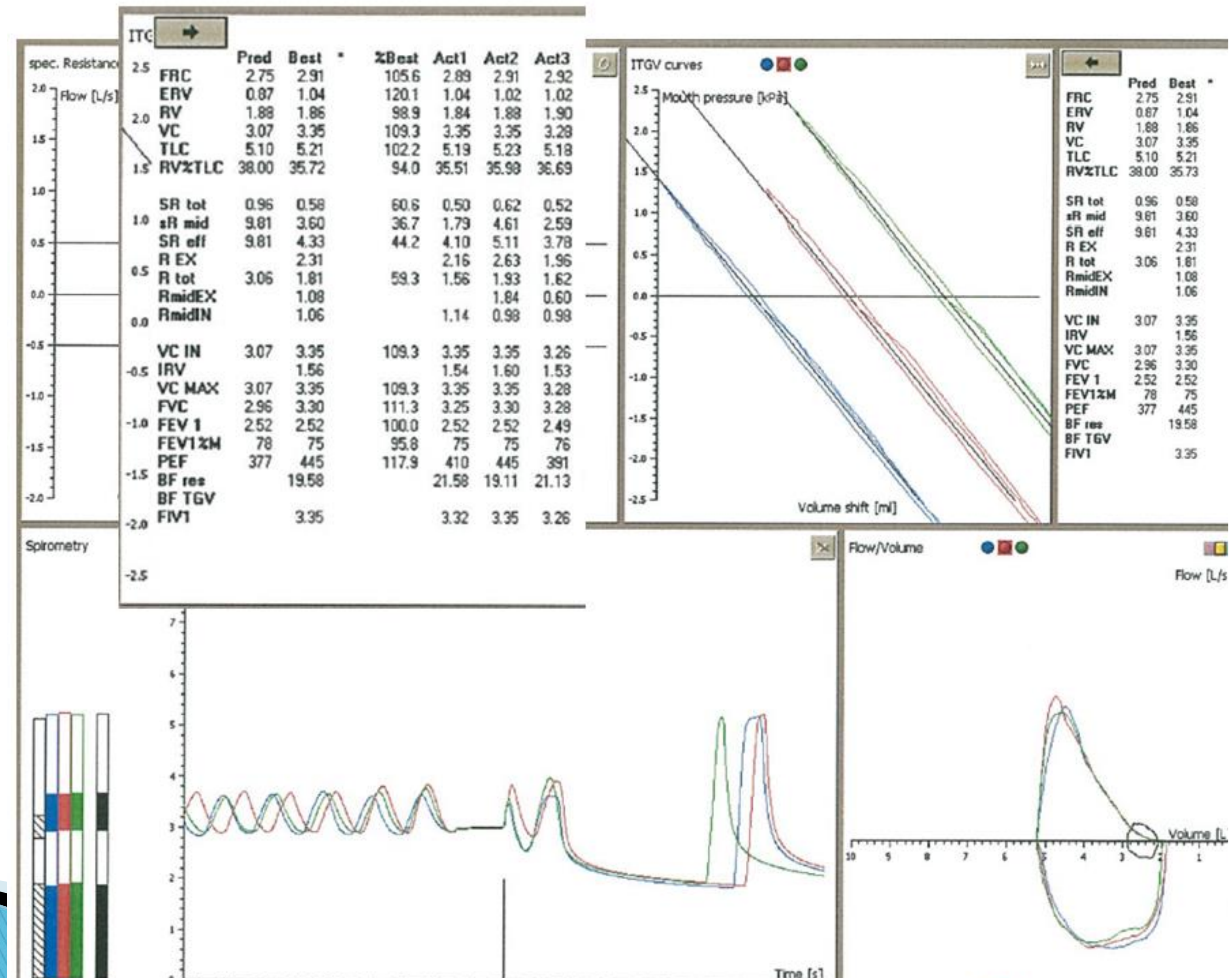
- TGV measurements:
  - The TGV loop should always be linear.
  - The source of error in computerized line fitting is usually electronic noise.
  - The line-of-best-fit should lie along the longitudinal axis of the loop.

# CLOSED SHUTTER




*TGV* = Delta Mouth Pressure / Delta Volume

# Review Repeatability and Switch-in Points



# Reporting Lung Volumes

- $FRC_{pleth}$ is mean of all acceptable efforts
  - $\leq$ 5% variability, (highest – lowest)/mean x 100
- ERV is mean of ERVs from acceptable linked* vital capacity (ERV then TLC or IC to RV)
- VC is largest acceptable linked VC

* Mean ERV should be close to largest ERV

# Result Reporting

- RV = mean $FRC_{pleth}$ – mean ERV
- TLC = RV + largest VC
- alternate TLC calculation:
  - $FRC_{pleth}$ and IC still linked but patient can't perform sustained exhalation
  - TLC = mean of 3 largest $FRC_{pleth}$ + IC sums
  - RV = mean TLC minus largest VC

# Data Review

**Lung Volumes:**

- Perform 3 – 5 acceptable trials
- Variability of $FRC_{pleth}$ should be within 5% of the mean.
- Compare with other methods of volume determination when available

# Data Review

- Volume Acceptability:
  - Compare the VC volume with the FVC volume
  - Alternative Method:
    - IC to TLC after shutter opens
    - TLC = mean of 3 largest $FRC_{pleth}$ + IC sums
    - Use the IC and ERV measurements from the largest acceptable VC maneuver to calculate derived values
  - Compare TLC from different methods
  - Compare VA from DLco and TLC from plethysmography
    - VA should <u>never</u> be higher

# Performance Standard
# Test Quality Review
### Lung Volumes

- Was the pre-shutter EELV stable for 3-10 breaths?
  - Respiratory rate reasonable for patient?
  - EELV (FRC) correctly assigned?
- Was the shutter closed at the correct level?
  - Start of tidal inspiration (target: within 0.20L of FRC)
- Effort correct (> 5 cm H20 and < 20 cmH20)?
- Was the TGV loop bidirectional (inspiratory and expiratory) and closed?
- Is assigned TGV slope correct?
- Parallel to TGV loop?
- RV and TLC points correctly assigned?

# Performance Standard
# Test Quality Review

## Airway Resistance/Conductance

- Was the volume small (i.e. 50-100ml)
- Was the Pant frequency ~ 1Hz (30-60/m) for TGV
- Was the Pant frequency ~1.5 -2 Hz (90-120/m) for Raw?
- Is there minimal hysteresis in the open shutter loop?
- Is the Raw loop measured in the +0.5 to - 0.5 L/sec range?
- Is the Raw slope parallel with the Raw loop?
- Are there at least 3 acceptable trials?
- Has repeatability criteria been met?
- Is the TGV slope parallel with the TGV loop?

# Performance Standard
# Test Quality Review

## Variability and Repeatability

- Is the $FRC_{pleth}$ variability less than 5%?
  - Variability = (max – min) / mean x 100
- Is the variability of SVC within 0.15L of the largest SVC?
- Is the variability for sGaw $\pm$ .01 of mean when below .17 or $\pm$ .02 of mean when .18 or greater?

# Airway Resistance

# Airway Resistance Performance and Patient Management

# Patient Management
## Reassurance

- Reassure the patient continually to relieve anxiety associated with the test or sitting within the cabinet
- The test will take 3-4 minutes
- The door can be released at any time from the inside (manufacturer specific)

# Patient Management Explanation

- Open-Door Phase
  - Thoroughly explain the procedure
    - Open shutter-"like a small piston"
    - Closed shutter-"try panting with your hand over your mouth"
      - Brief, gentle efforts
    - Cheeks **must** be supported by hands
  - Demonstrate the maneuver
  - Practice with the patient
  - Emphasize relaxing and breathing normally between measurements
- Closed-Door Phase
  - Practice while waiting for thermal stability

# Patient Management Explanation

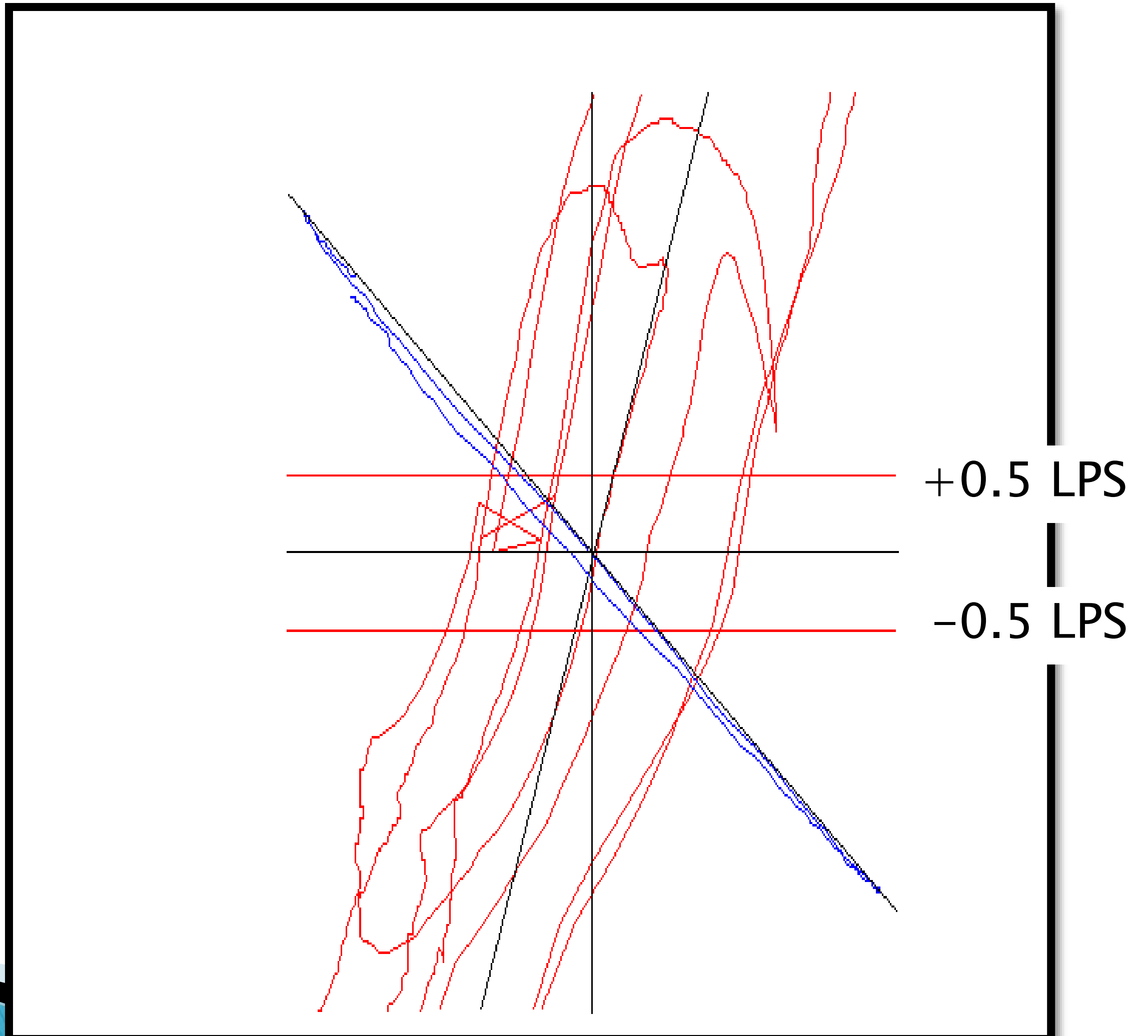
- Patient performance criteria
  - Small breaths (~50-100ml)
  - Emphasize consistent, gentle efforts between 1.5 - 2 efforts/sec (90 to 120)
  - Relax between efforts
  - Emphasize this is NOT an MVV or MIP/MEP
  - Provide continuous feedback on performance

# Patient Management Coaching

- Provide real-time feedback
- Practice maneuver prior to door closure
- Practice maneuver after door closure
- Evaluate and correct during testing

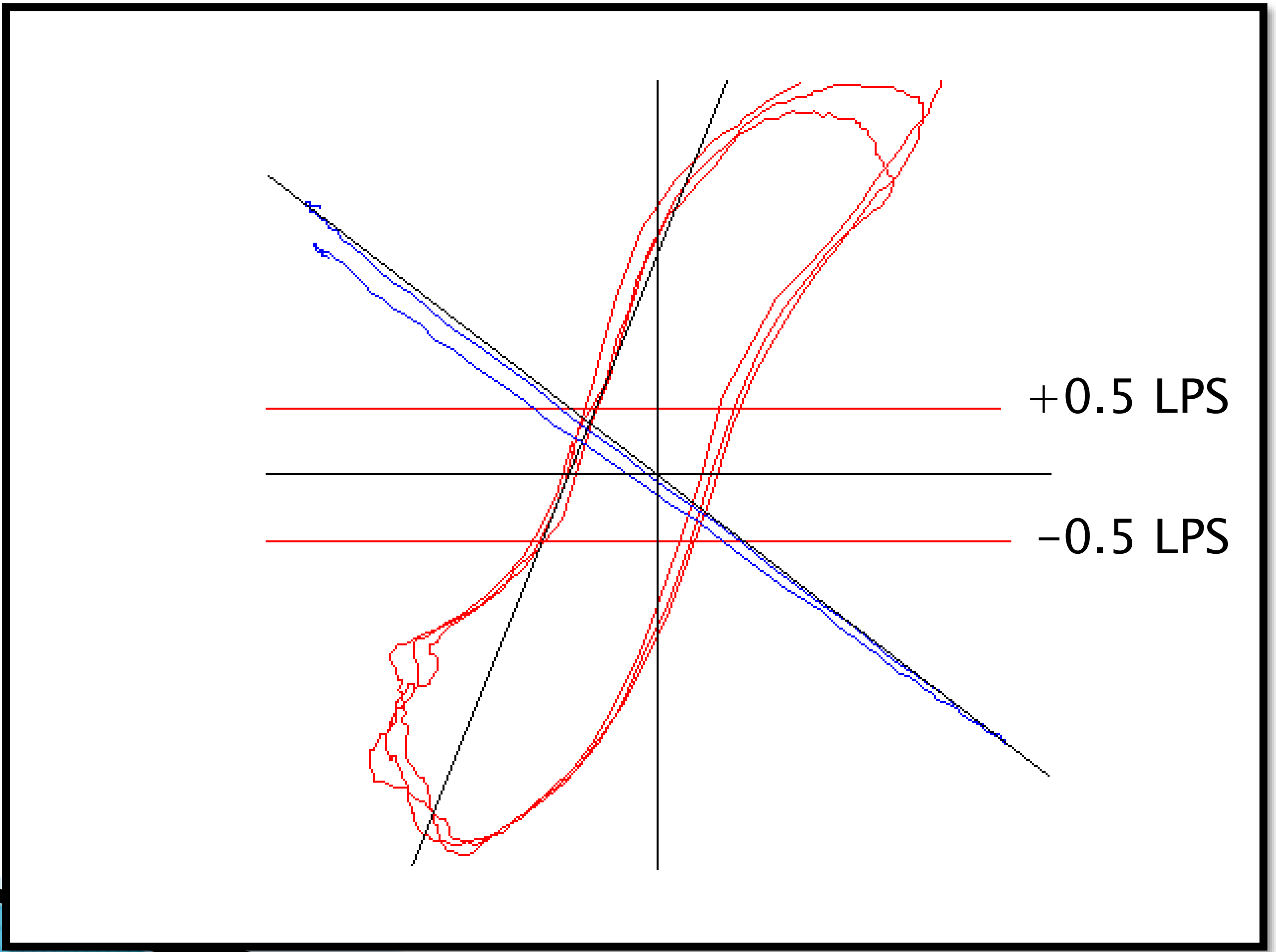
# Open Shutter Panting Too Big

## Ends of Loops are Off Screen



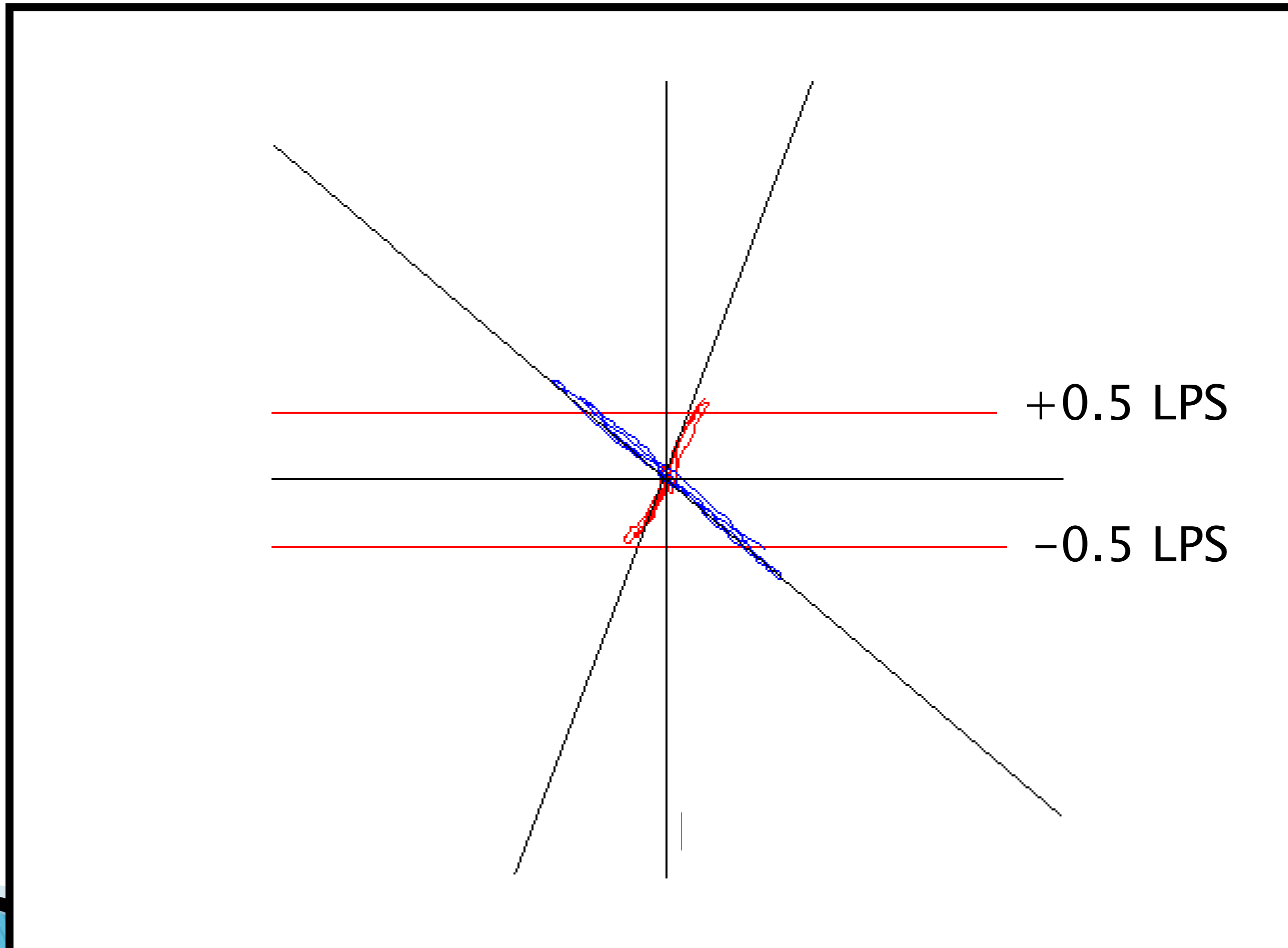
# Open Shutter Panting Still too Big

## Loop is also too wide

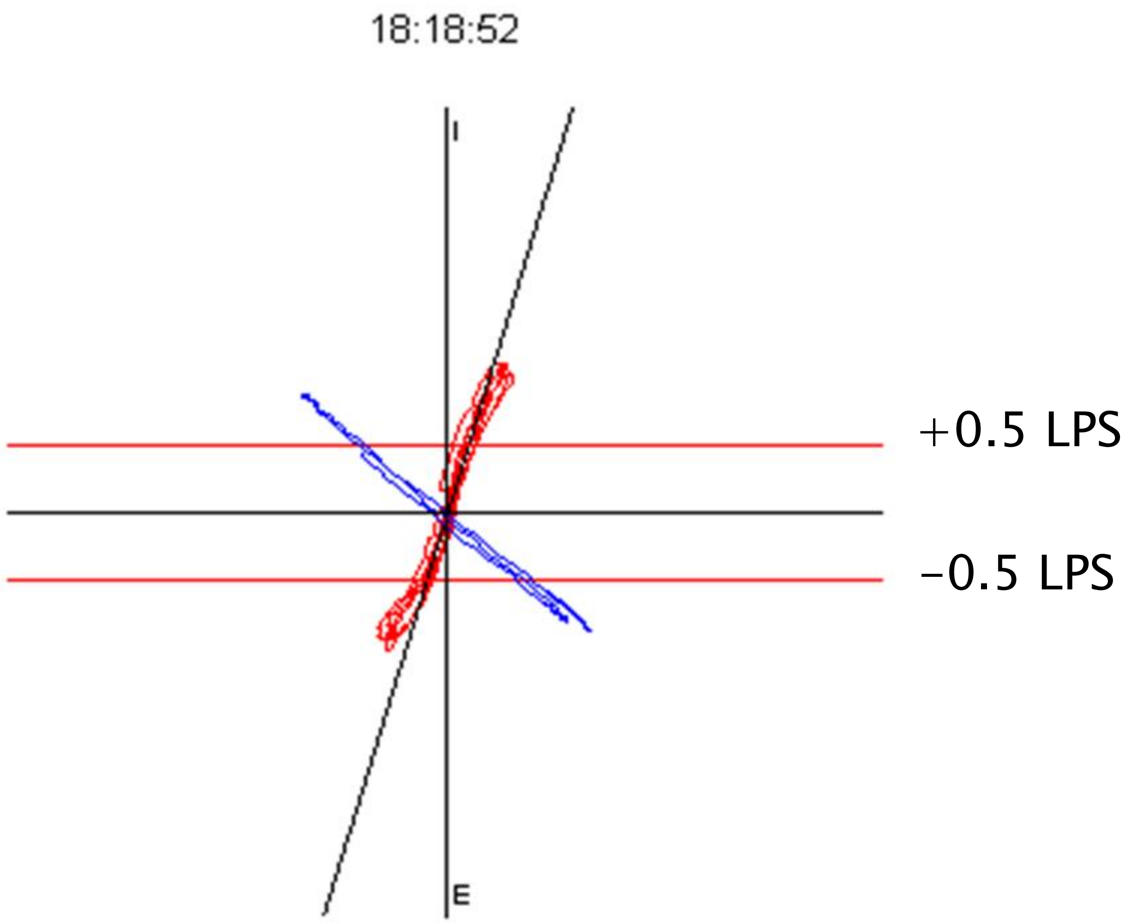


# Open Shutter Panting Too Small

## Expiratory flow less than 0.5LPS



# Airway Resistance and Conductance Correctly Performed



# Data Review

## Airway Mechanics: $R_{aw}$ loop

- The measurement  is generally made a loop intersection with +0.5 and –0.5 L/sec horizontal markers

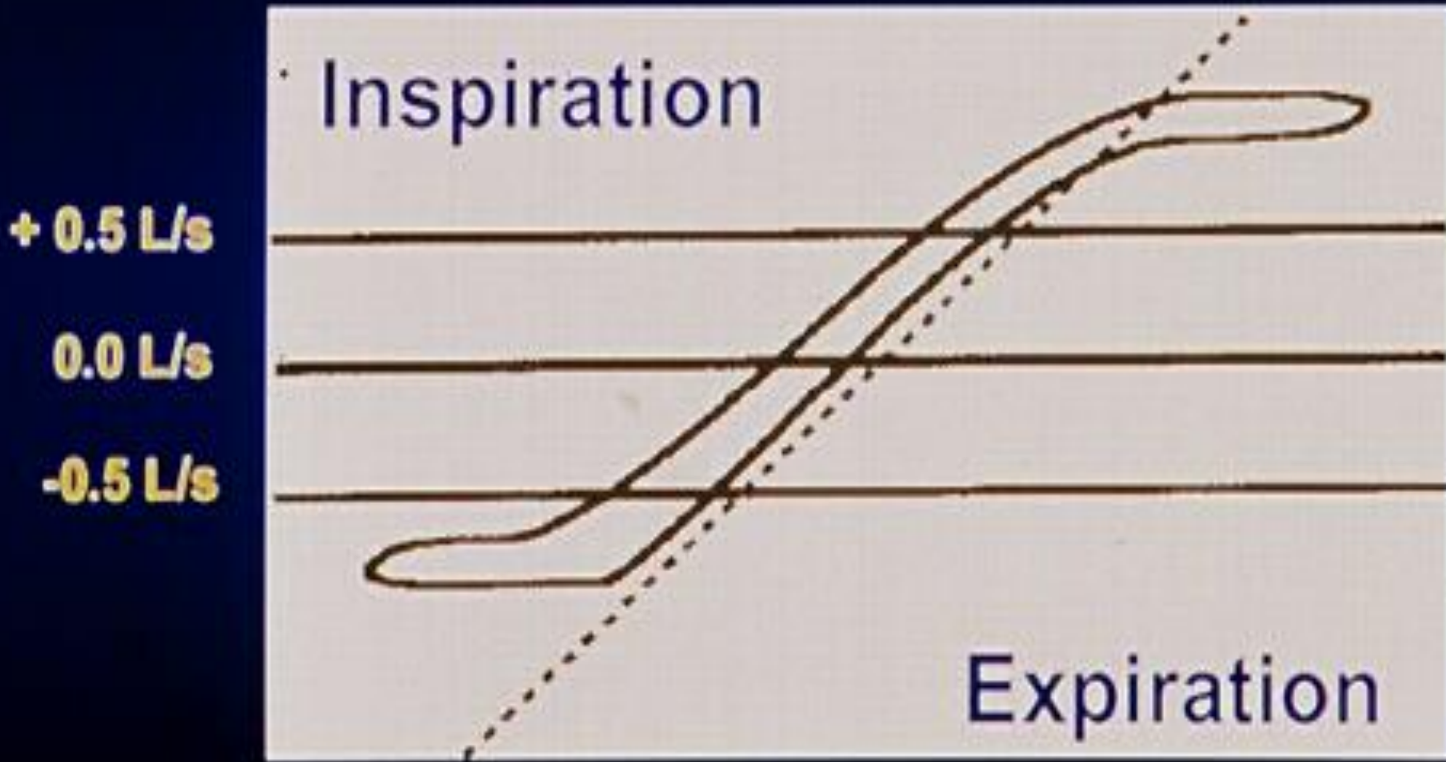
- When the loop appears aberrational in the +0.5 and –0.5 L/sec segment, measure through the larger linear portion of the loop.

- Most importantly, STANDARDIZE the method of measurement in your lab.

# $R_{aw}$ Acceptability Criteria

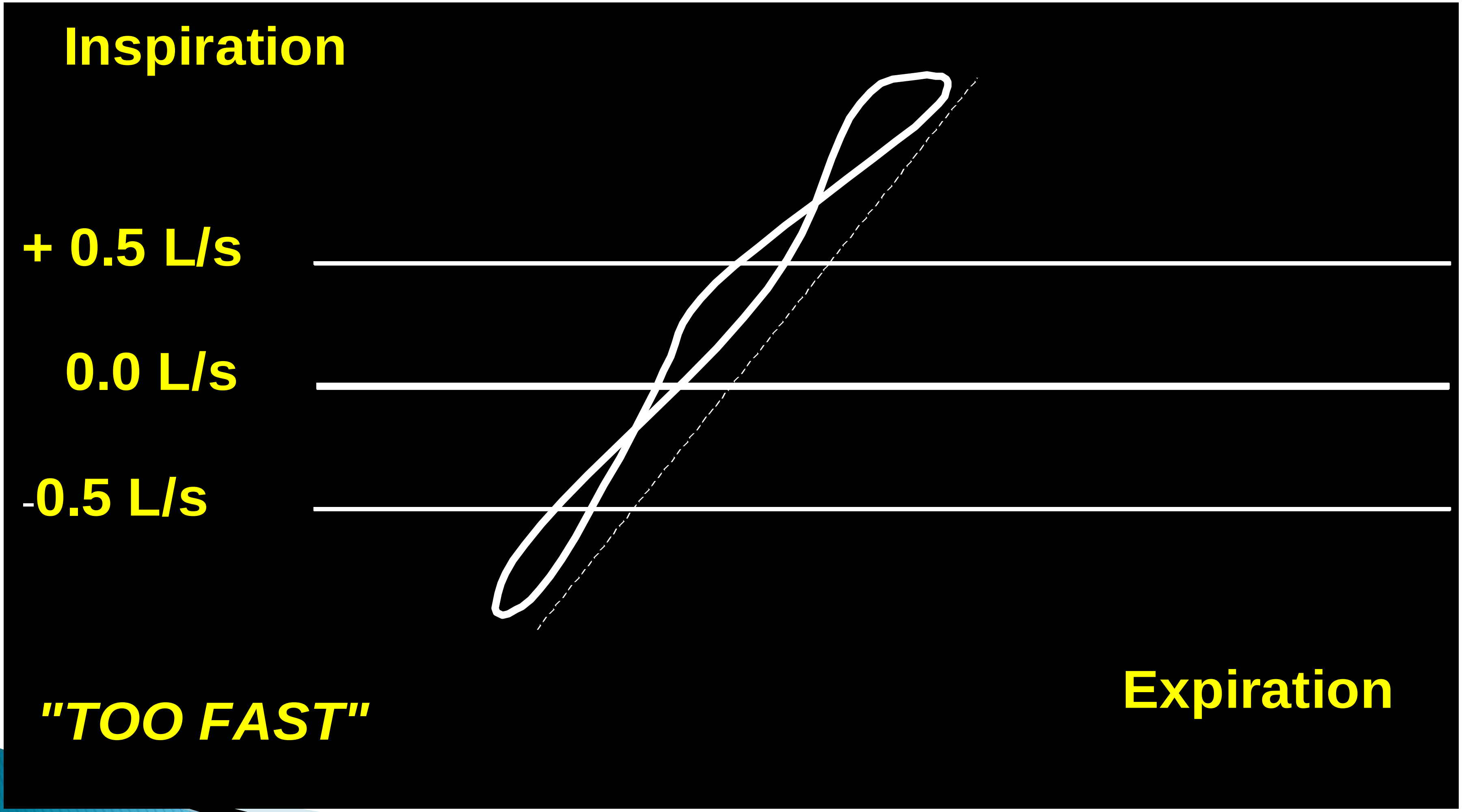
- Panting frequency should be ~ 90 –120 breaths/minute
- open–shutter loops are linear, non–elliptical and closed (or nearly so)
- intersection of loops with +0.5LPS and –0.5LPS used to construct slope
- Average of 4–5 acceptable trials
- sGaw variability is $\pm$ .01 of mean when below .17 or $\pm$ .02 of mean when .18 or greater

# Airways Mechanics
# Open - Shutter Loop Morphology

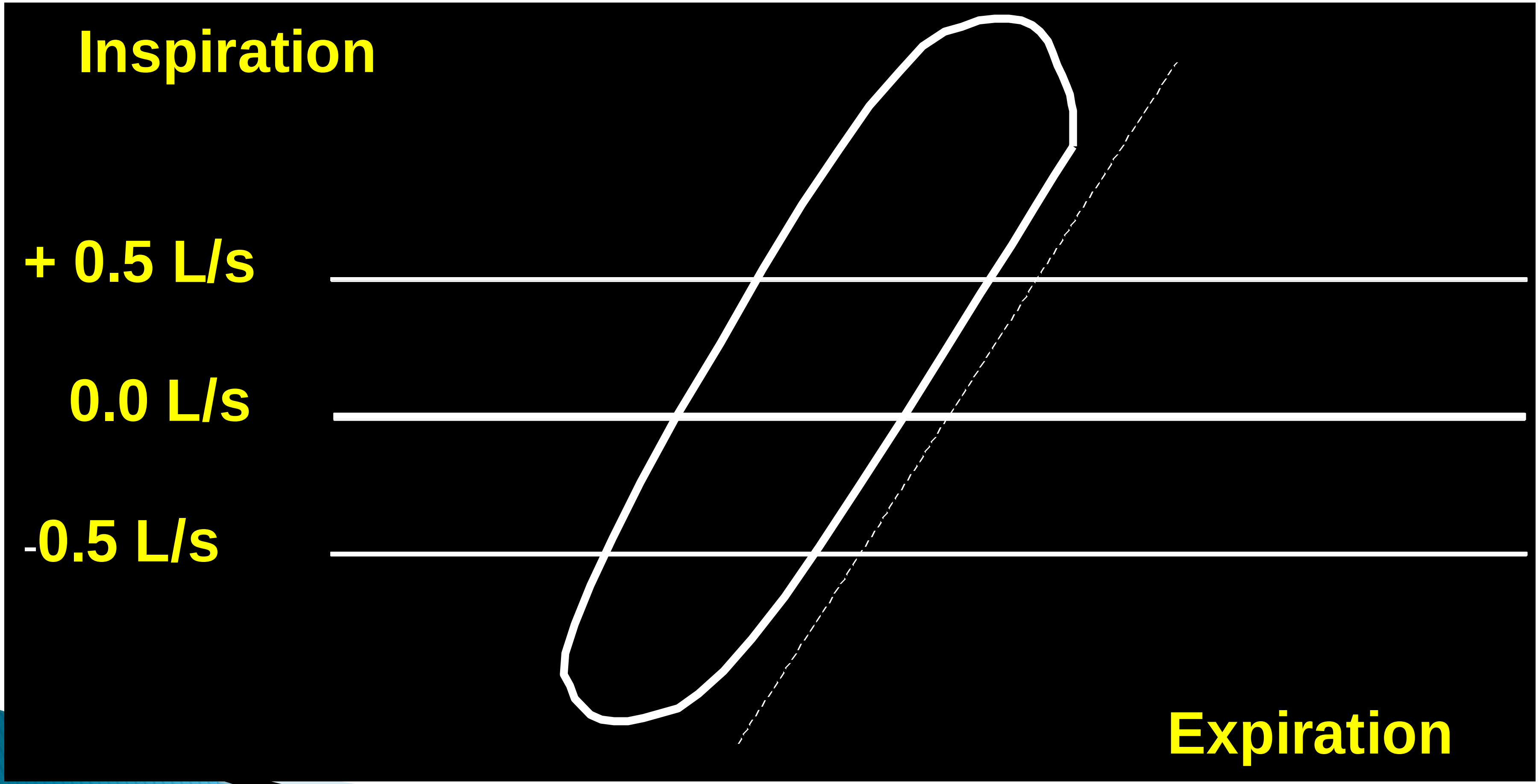



"Fixed Extrathoracic Lesion"

# Open-Shutter Loop Morphology



# Open-Shutter Loop Morphology



# Airway Collapse Pattern

Airway Collapse Patterns may be better represented by separating Rinspiratory and Rexpiratory