DLCO and Lung Volumes

Workshop Notes 2018

Tony Kajnar, RRT/AA, RCPT(P)
Senior Therapist, Sault Area Hospital PFT Lab
kajnart@sah.on.ca

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Affiliations

- Sault Area Hospital: Pulmonary Function Lab
- Canadian Pulmonary Function Symposium: CACPT
- RTSO: Pulmonary Diagnostics group
- Consultant for Methapharm Inc

DLCO and Lung Volumes

- Review DLCO testing
- Review Lung Volumes by plethysmography testing
- Hands on demo/practice

Lung Diffusion

DLCO terminology

- Referred to as Diffusion Capacity (DLCO) or transfer factor (TLCO)
- DLCOuncor – transfer factor for carbon monoxide ml/min/mmHg
- DLCOcor – DLCO corrected for Hgb
- VA – alveolar volume (litres)
- DL/VA – transfer factor relative to alveolar volume

10 second breath holding techniques

Alveolar gas using sample bag

- Ensure sufficient sample size and analyzer response
- Older method
- Test gas: 10% He, 0.3% CO, balance air

Rapid response gas analyzer

- Test gas: 0.3% CH4, 0.3% CO, balance air
- Detect tracer gas in real time
- Ensures alveolar sample measured
- Verifies that RV dilution isn’t affecting measurement

Factors which affect DLCO: Instrument

- Follow manufacturer's recommendations for testing
- Instrument variability
- DLCO sample gas
- Analyzer calibration
- Analyzer linearity
- Analyzer response time
- Volume calibration
- Instrument dead space (filters, mouthpiece, tubing)
- Altitude

Factors which affect DLCO: Patient

- Hgb level, COHgb, CO2 levels, FIO2, lung volume, disease
- Smoking, exercise, body position, menstrual cycle,
- Leaks, valsalva, mueller maneuvers during breath hold
- Inspired volume
- Inspiratory or expiratory flow
- Inspired oxygen concentration

Patient preparation

- Avoid large meals, smoking, ETOH, strenuous exercise prior to testing
- FIO2 .21 > 10 mins (if possible)
- Confirm sources of CO exposure (heavy equipment, industrial)
- Seated and resting for 5 mins prior to testing
- Seated and resting between trials
- Best SVC should compare to Vi (inspired volume)

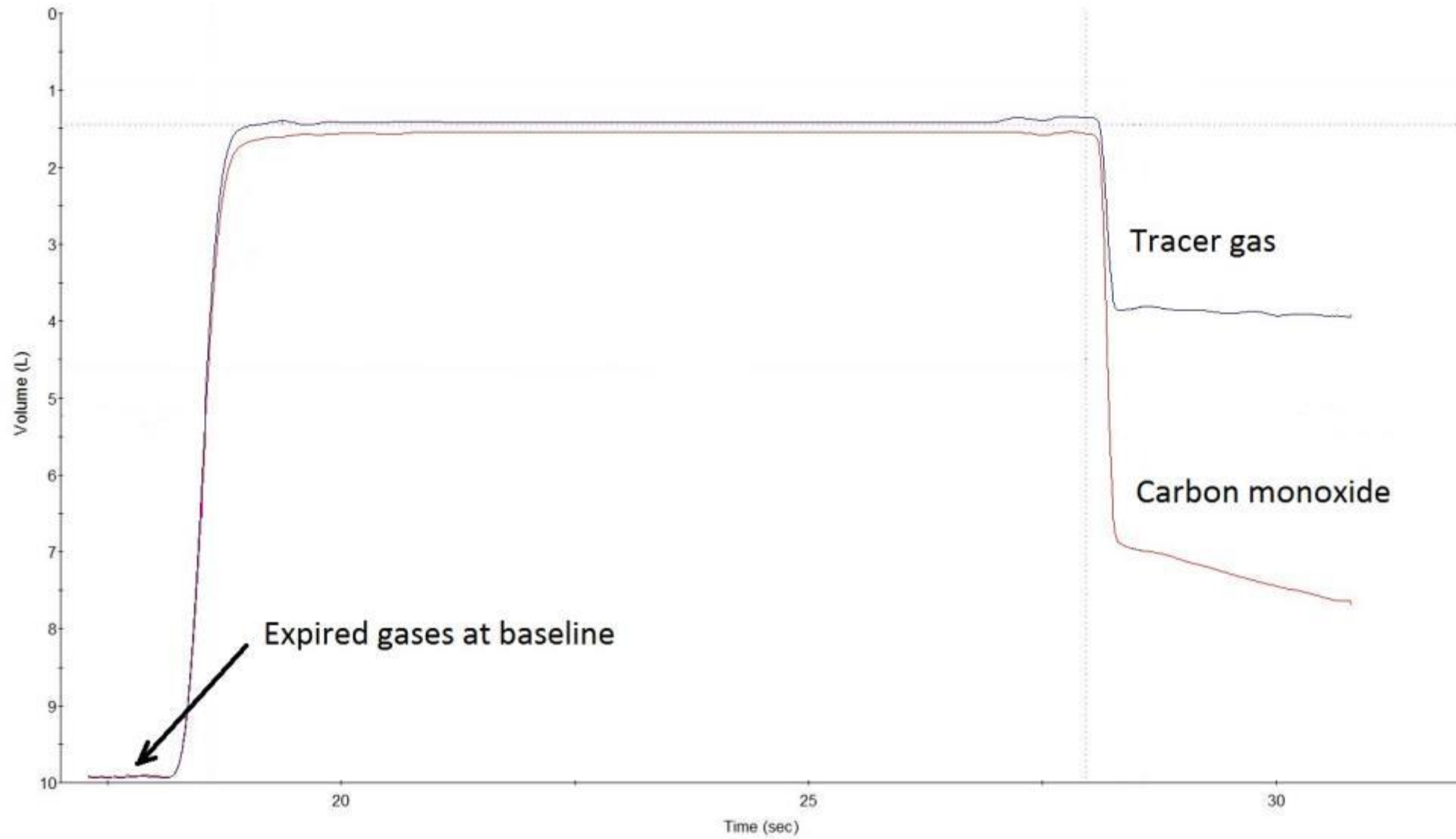
2017 ATS/ERS DLCO update

- New recommendations not intended to render older systems obsolete but to outline improvements for current and future PFT systems
- Greater detail to tighten measurement, repeatability and reporting criteria
- Detailed technical specifications and performance for Rapid Gas Analyzers (RGA) and tracer gas.
- Flow and gas analyzers zero before each measurement
- Update recommendations for quality assurance
- Recommendations for further study for predicteds, reporting, correcting for Hgb, CO_2 retention

Single breath diffusion of the lung (DLCO)

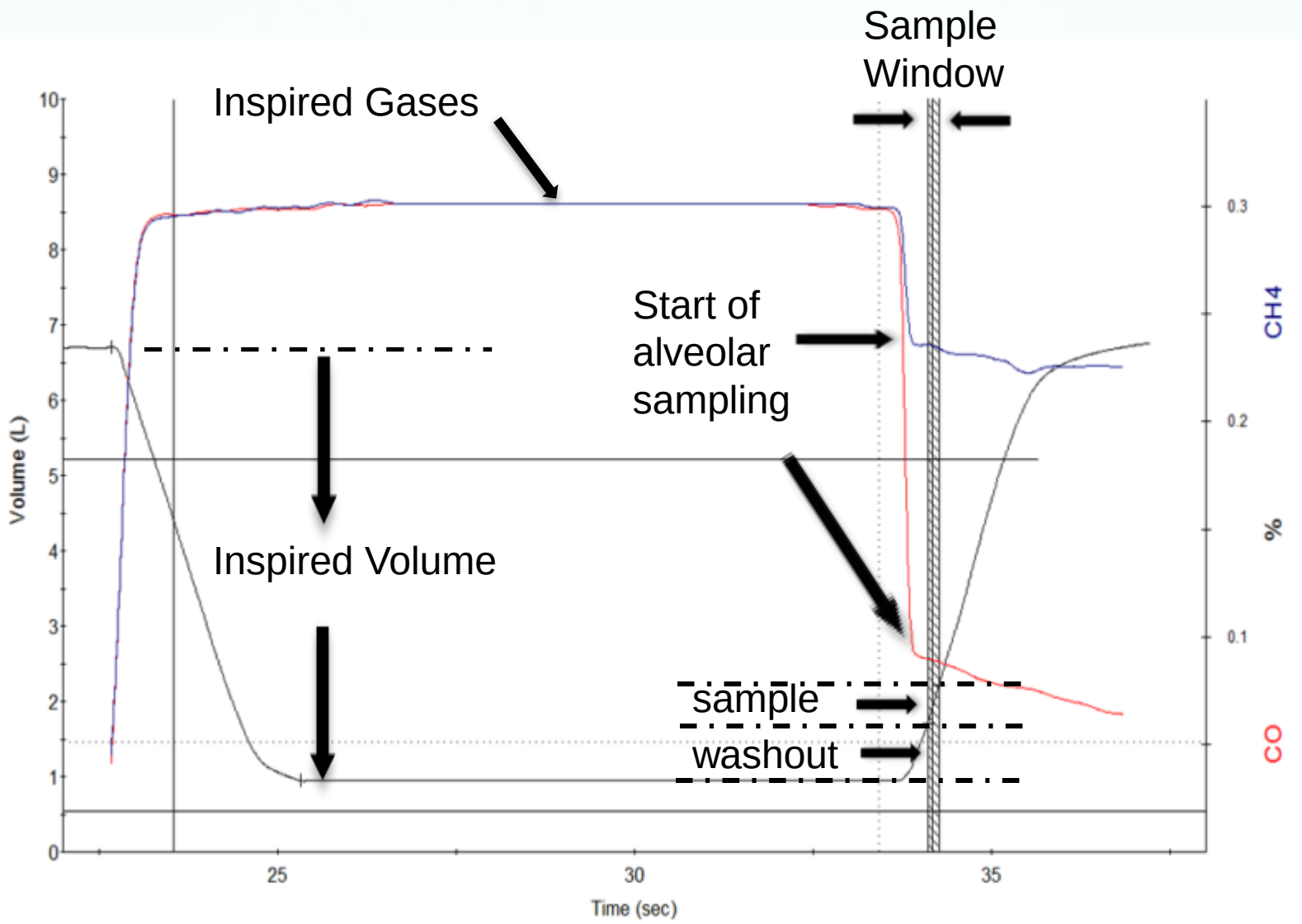
- Ensure maximal Vi (inspired volume). Target is 90% of best VC (from SVC or other maneuver)
- Washout volume: anatomic and mechanical dead space must be discarded (washed out)
- Sample volume: ensure alveolar gas is being sampled
  - Rapid analysis with demand valve. Measure DLCO after deflection point once trace gas plateau starts
  - CO analyzer response time in older bag systems: ensure that DLCO was stable and at atmospheric pressure
- Trace gas is inert and insoluble: accounts for the RV that dilutes the inspired gas sample

Tracer and sample gas RGA



Measuring tracer gas at baseline:

- Confirms washout of test gas from previous measurements (< 2% of test gas)
- Pre-inspiratory tracer gas level in V_A calculation
- Exhaled CO level can be used to adjust for CO back pressure


Sample Window
Inspired Gases
Start of alveolar sampling
Inspired Volume
sample
washout
Volume (L)
Time (sec)
CH4
CO
%
0
1
2
3
4
5
6
7
8
9
10
25
30
35
0.1
0.2
0.3

DLCO sequence

- Relaxed tidal breathing
- Exhale completely to RV (up to 12 seconds)
- Inhale fully and smoothly to TLC (Vi ≥ 90% best VC, insp time <4 sec, ensure continuous flow)
- Relaxed breath hold time (8-12 sec)
- Exhale with a steady breath during sampling (< 4 sec)
- Repeat after 4 minutes of rest. Verify with tracer gas baseline (some gentle deep breaths or longer time between test trials may be required for washout)

Expiratory phase

- Exhale smoothly during sampling (< 4 sec)
- Washout volume (750 – 1000 mls): amount of sample that will be bypassed prior to analysis
- For VC < 2L may need to use washout of 500 mls
- Sample volume (500-1000 mls): amount of volume during alveolar sampling
- Note: many RGA systems automatically determine appropriate washout and sample volumes based on patient's VC. Some older systems may require these to be entered manually.

Acceptability Criteria

- Vi ≥ 90% of largest VC
- alternatively ≥ 85% of largest VC if V_A within 200 mls or 5% (whichever greater) of largest V_A from other acceptable DLCO trials
- Inspiratory time < 4 s
- Stable breath-hold (10 ± 2 s) without leaks, valsalva or müller
- Sample collection within 4 s of start of exhalation
- New quality grading scores (QC from A-F)

Repeatability Criteria

- Repeatability within 2 ml/min/mmHg of at least 2 acceptable tests
- 4 minutes between efforts (or longer for washout of tracer gas in obstructive disease)
- More than 5 measurements not recommended
- COHgb increased 0.6-0.7% each measurement (increase CoHgb ≈ 3.5% from baseline after 5 measurements)

DLCO QC quality grading scores

Score	Vi/VC	tBH	Sample collection
A	≥ 90%	8-12 S	≤4 s
B	≥ 85%	8-12 S	≤4 s
C	≥ 80%	8-12 S	≤5 s
D	≤ 80%	<8 or > 12 s	≤5 s
F	≤ 80%	<8 or > 12 s	>5 s

Modified from ERS/ATS standard

Quality Control

http://www.nichemedical.com.au/hans_simulator.shtml

DLCO syringe quality control

Syringe QC (mechanical QC)

- Test syringe as patient: ATP mode, Syringe Mode, BTPS off
- DLCO = < 0.5 ml CO/min/mmHg
- IVC 2.85 – 3.15 @ATPS
- VA 2.90 – 3.36 3 @ATPS
- Weekly leak test of test syringe, ensure syringe is validated
- Ensure system deadspace: manufacturer specification, filter, patient circuit adjuncts

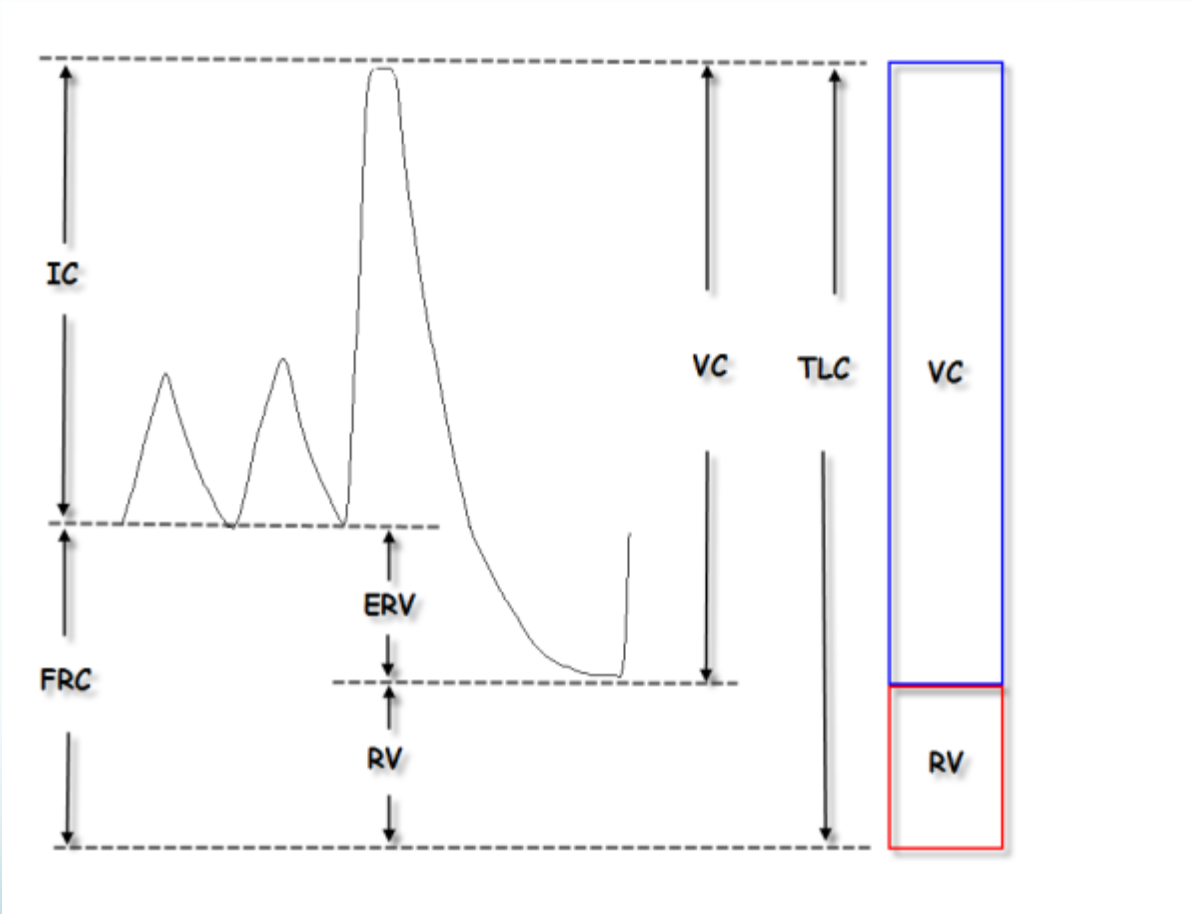
Quality Assurance

- Within 2 SD, CV 6-7%
- Maintain a log book or digital log book
- Inventory of each workstation, date of purchase, cost, purchase status (new or used), serial numbers, workstation ID, validation performed
- Perform and document mechanical and Bio-QC
- Preventative maintenance (PM): document routine replacement and validation/recertification
- Infection control routine

Lung Volumes by plethysmography

Lung Volumes

inspiration



Basic definitions

- Hertz (Hz): number of cycles per second
- TLC: Total lung capacity. Volume of gas after maximal inspiration, or the sum of all volume compartments
- TGV: thoracic gas volume. Compressible volume in the lungs – should be measured at FRC
- FRC: functional residual capacity. Volume of air in the lungs at the end of resting tidal breathing
- RV: residual volume. The volume in the lungs after maximal expiration, regardless of starting volume

Indications for lung volumes

Differentiate between restriction and obstruction

- Increased TLC = hyperinflation
- Increased FRC or RV = air trapping

Additional data to support or exclude diagnosis:

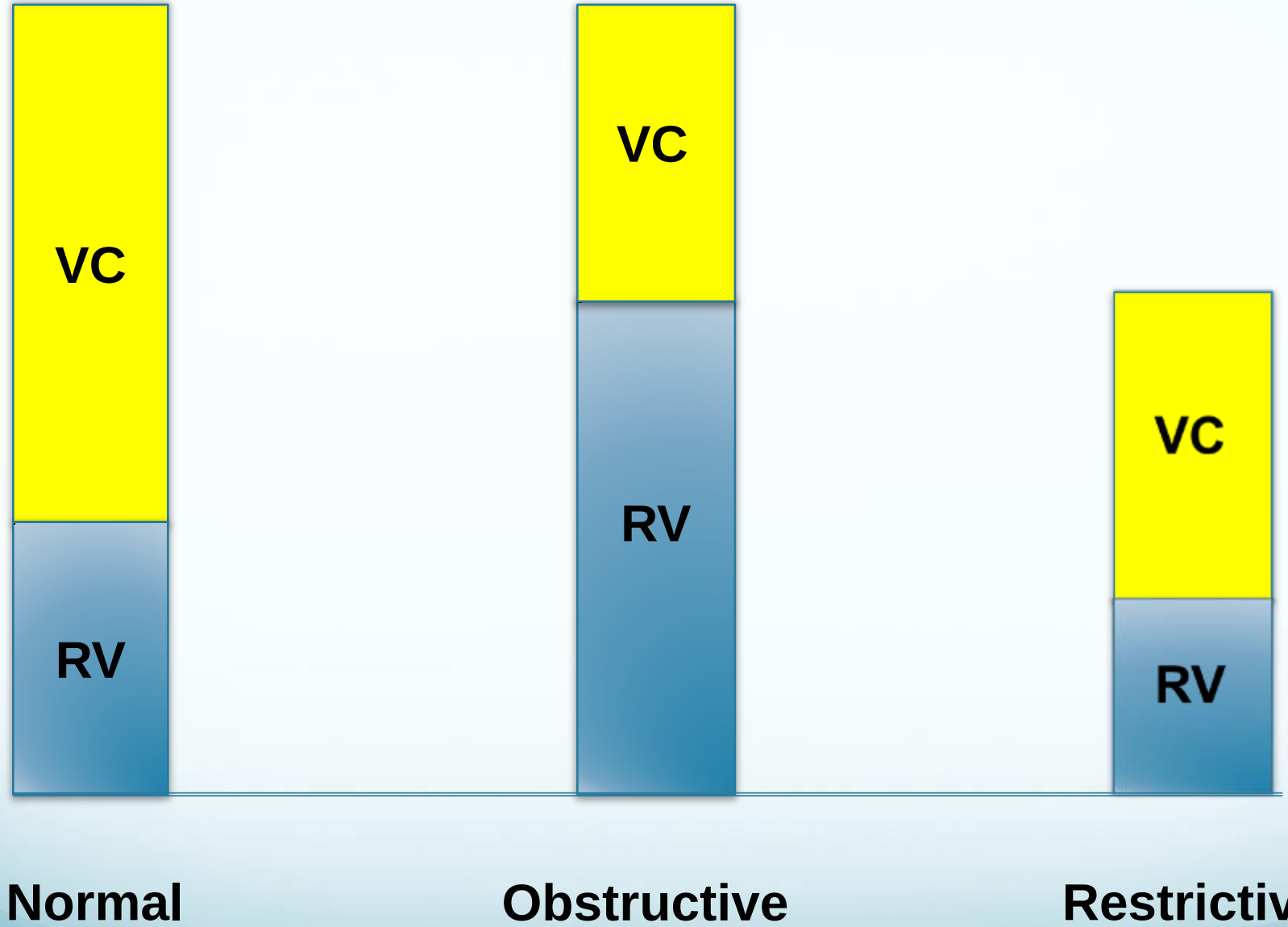
- TLC, FRC, RV, RV/TLC, IC/TLC

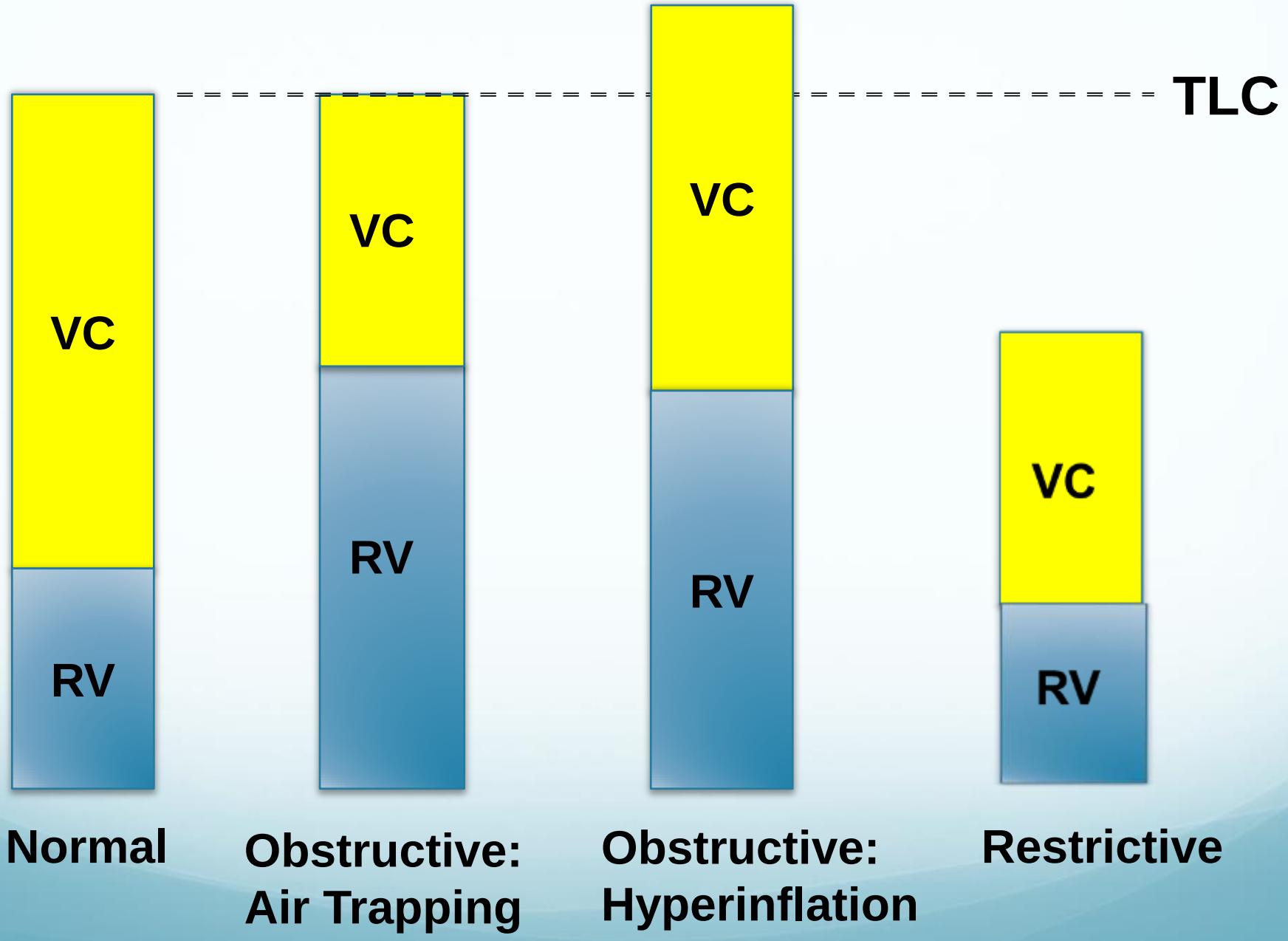
Useful for monitoring:

- ILD, COPD, asthma, lung transplant, GVHD, drug toxicity, autoimmune conditions

Lung Volumes patterns

- Normal
- Obstructive: hyperinflation, air-trapping (or both)
- Restrictive: decreased lung capacity and volumes


VC
RV
VC
RV
VC
RV
Normal
Obstructive
Restrictive


TLC
VC
RV
VC
RV
VC
RV
VC
RV
Normal
Obstructive:
Air Trapping
Obstructive:
Hyperinflation
Restrictive

Clinical assessment and categorization

- Objective measurements to help categorize impairment and degree of severity
- Obstructive lung disease associated with air-trapping and hyperinflation
- Air-trapping and hyperinflation in asthma can be reduced with treatment whereas reduction may not be appreciated in COPD. Post B/D lung volumes could provide added assessment
- Restrictive lung disease associated with reduced lung volumes

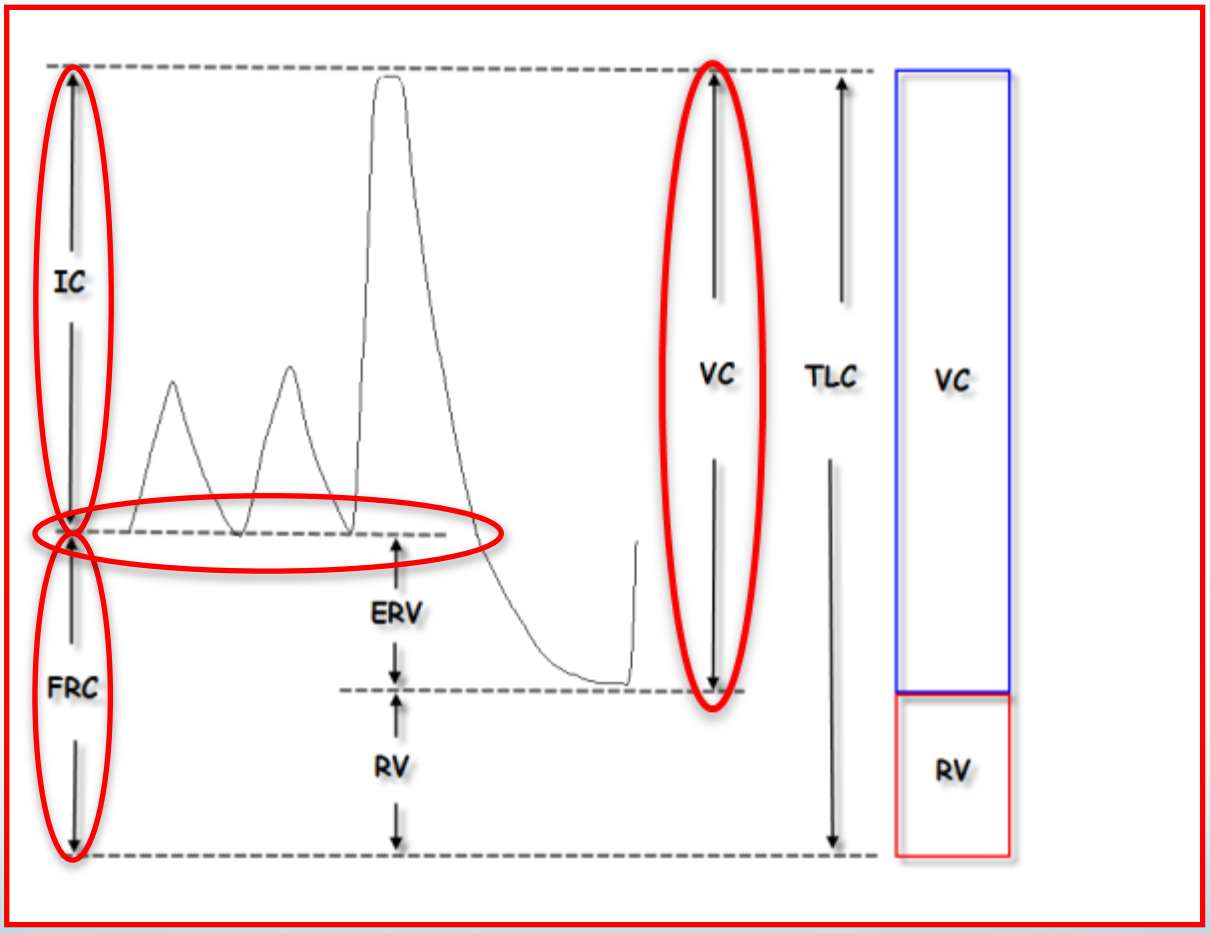
FRC measurement

- Dilutional methods
  - He dilution
  - Nitrogen washout
  - May underestimate lung volumes as not all airways are
- Body plethysmography
  - Measures all gas in the thorax
  - Quicker
  - Good repeatability
  - Also allows for RAW and sGAW measurements
  - May be difficult for some patients to tolerate

Pre-test considerations

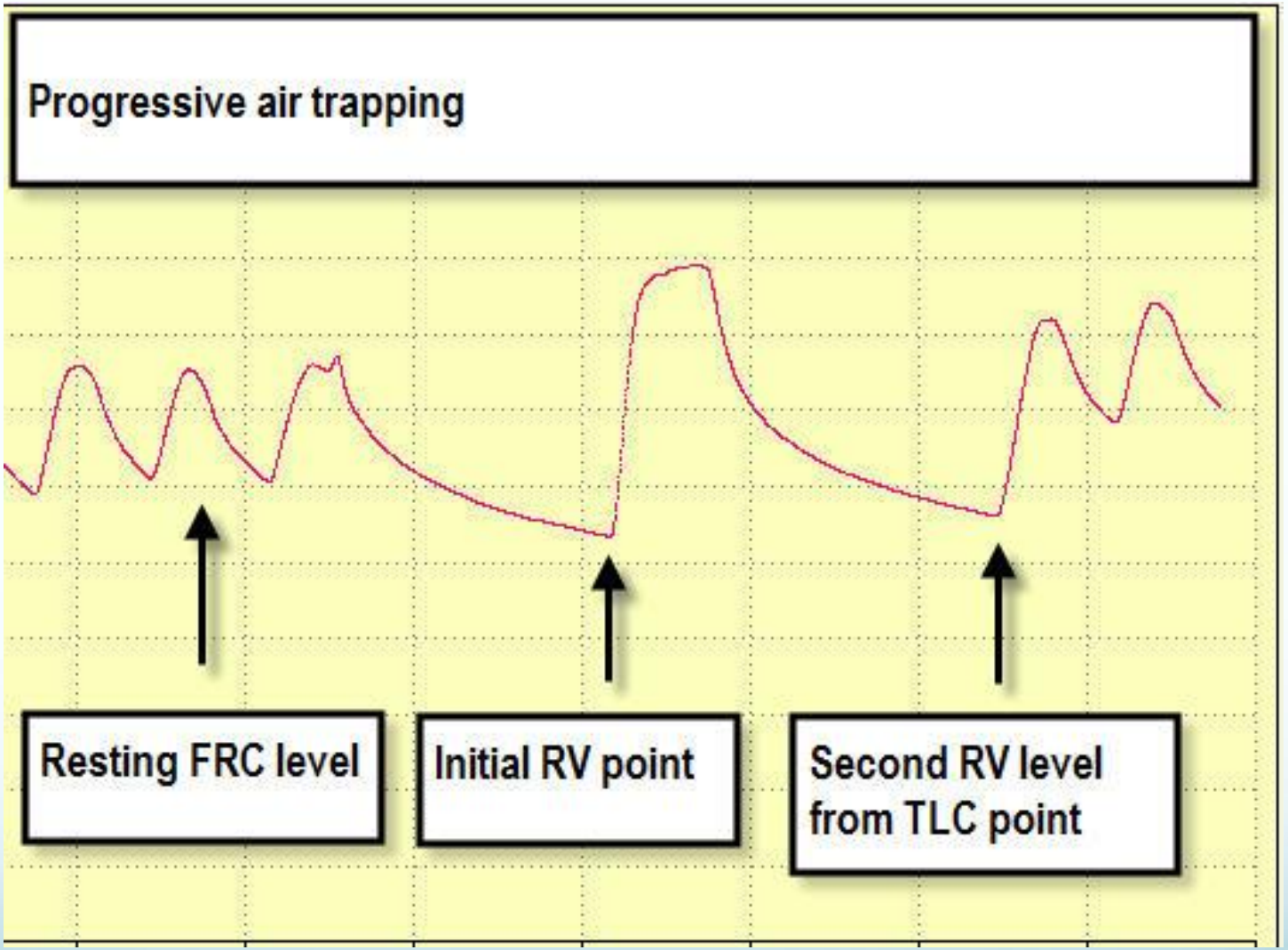
- Calibration
  - Volume
  - Mouth pressure
  - Box pressure
- Quality control
  - QC: bio-QC, mechanical QC
  - Reported data
  - Technologist statements
- Patient preparation

Lung Volumes: essential measurements



Ensure quality: Patient

- Relaxed, normal breathing baseline: is FRC point stable?
- Know where FRC is and ensure measurement of TGV is at FRC: shutter closed at correct volume
- Panting volume (<50 mls)
- Panting frequency (≈ 1 Hz or 30-60/min)
- SVC manoeuver prior to lung volumes helps patient practice. Ensure stable resting tidal breathing at FRC
- Mean IC and best VC from separate SVC maneuver can be considered for use if not obtained as a linked sequence
- Monitor for progressive air-trapping or poor IC


Progressive air trapping
Resting FRC level
Initial RV point
Second RV level from TLC point

Challenges

- More complex for patient
- More complex for operator
- Specialize equipment required
- Some patients won’t tolerate testing
- Lung volumes may be over-estimated in patients with severe obstruction – must recognize sources of error during measurement
- Ensure accuracy of FRC (TGV) angles

Door open stage

- Explain and demonstrate proper depth and frequency
- 60 times a minute, “like tick-tock of a clock”
- Use mouthpiece, demonstrate occlusion with hand, continue without exaggerating movement
- “need to measure pressures in your lungs”
- “pumping like a piston”, “panting gently”
- “gentle, equal movement of air from your chest”,
- Mouthpiece will block, continue pumping/panting without changing depth or effort

Door closed phase

- Ensure patient can hear you. Advantage if you are able to hear the patient
- Observe patient
- Use time for thermal equilibrium to review steps, speaking to patient may help keep them relaxed
- Practice steps as necessary prior to attaching to mouthpiece
- Support cheeks
- Maintain seal
- Review proper position

Patient positioning

Panting phase

- Volumes during panting ≈50 ml
- Loops appropriate: size ± 10 cmH2O
- “panting” rate of 0.5 – 1 Hz (30-60 bpm). i.e. metronome, tick tock of a clock, keep time like the drummer in a band
- Frequency of TGV panting (30-60/min) is slower than panting during RAW (90-120/min) to avoid under-estimation of TGV
- Ensure that shutter is closed at FRC. Minimize switch in error
- Provide calm, relaxed feedback in order to maintain proper performance

Sequence

- Stable, relaxed tidal breathing at FRC (end tidal) level: 3-4 breaths
- Occlude shutter: measure 3-4 panting cycles
- “panting” rate > 1.5 Hz can underestimate TGV
- “panting” rate < 0.5 Hz can cause errors due to controlled leak of bodybox
- No artifacts (hysteresis, closed loops, no leak, drift)
- Often easier to perform RAW testing sequences first then move on to TGV measurements but be careful to monitor appropriate panting frequency

ATS “preferred” method: Linked Method

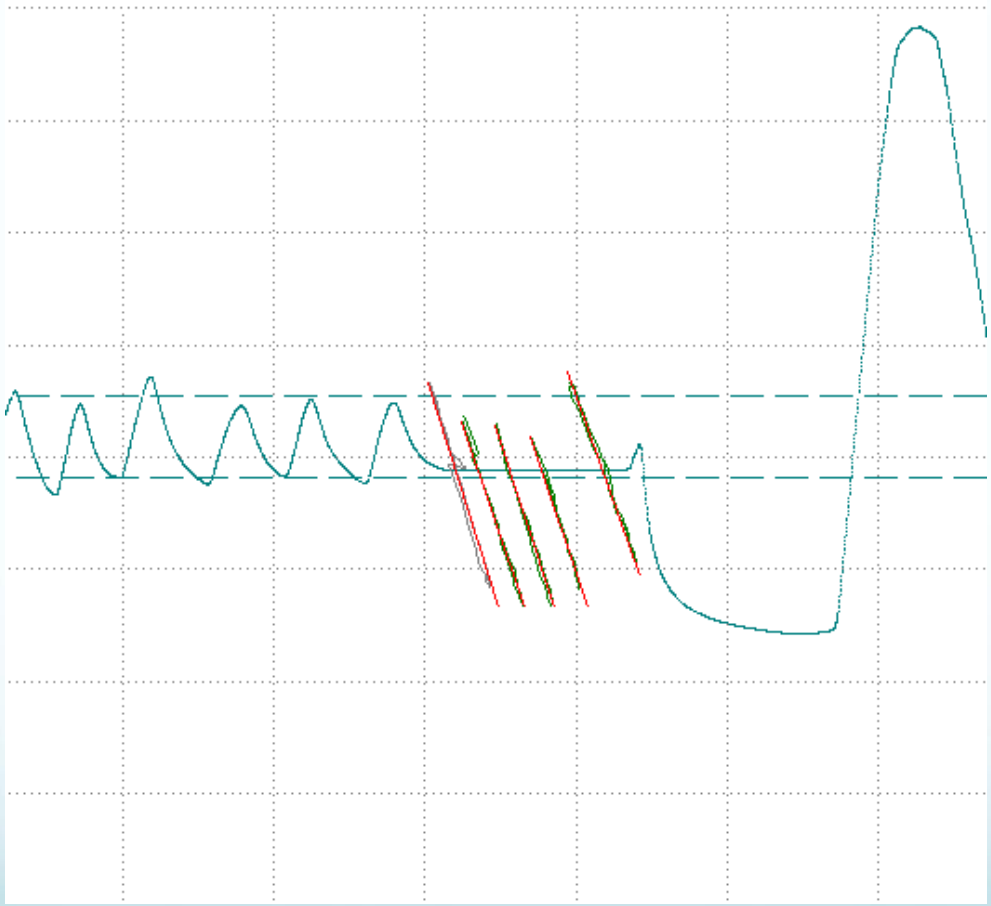
Linked process:

- tidal breathing → occluded panting at FRC → open shutter and exhale completely to RV → IVC to TLC point

Calculations

- RV = FRC(mean) – ERV(mean)
- TLC = RV + VC(best)

“preferred” linked method example



ATS “preferred” linked method

FRC reported as the mean of acceptable FRC linked to ERV and IVC trails

RV obtained from FRC point preferred over RV obtained from TLC point

ATS “alternate” linked method

Linked:

- Tidal breathing → occluded panting at FRC → inspire to TLC point (IC) → SV to RV point

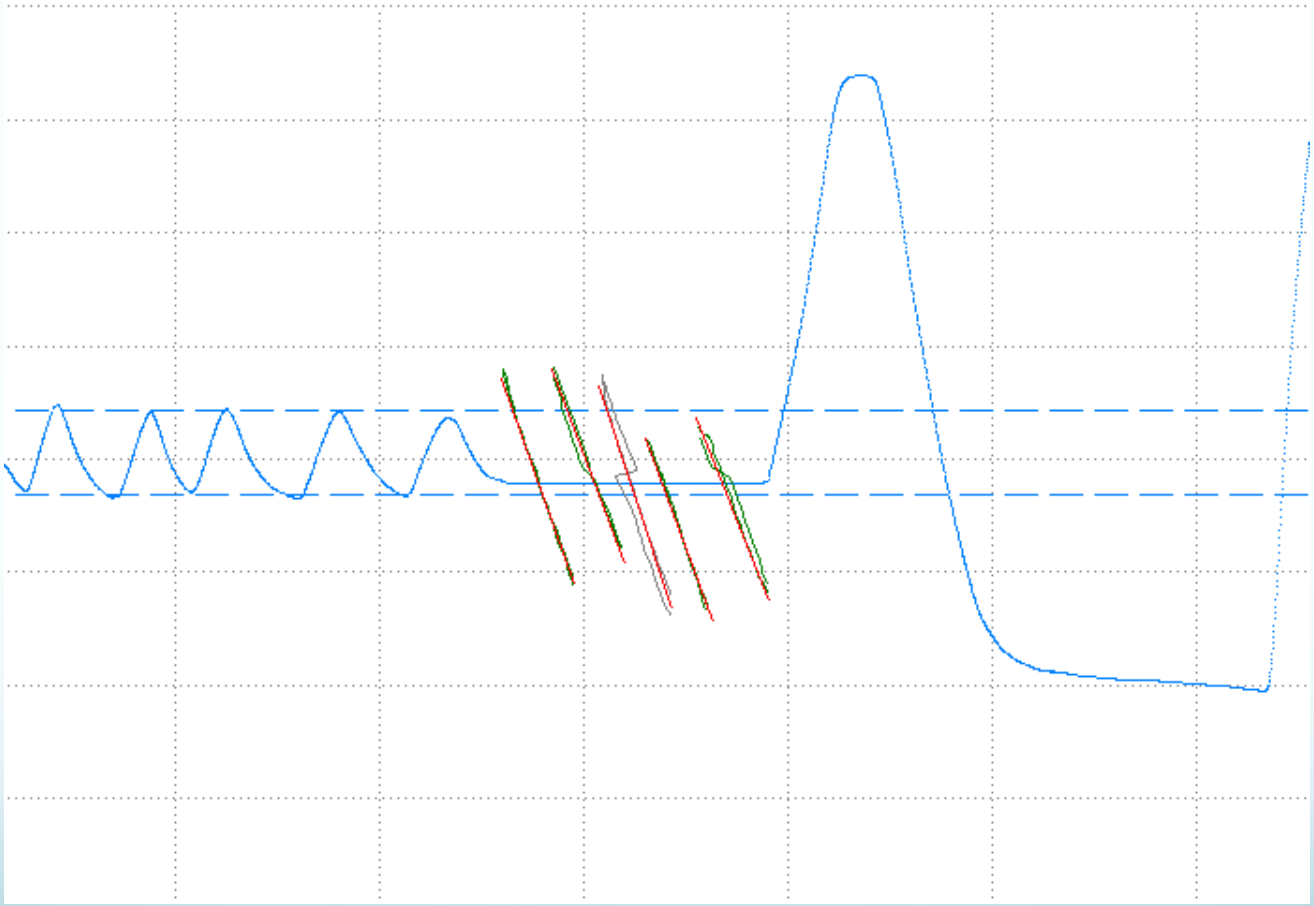
Calculations

- TLC = FRC (mean) + IC (mean)
- RV = TLC – VC (best)

May import SVC from a separate test

May be better tolerated by some patients

“alternate” linked method

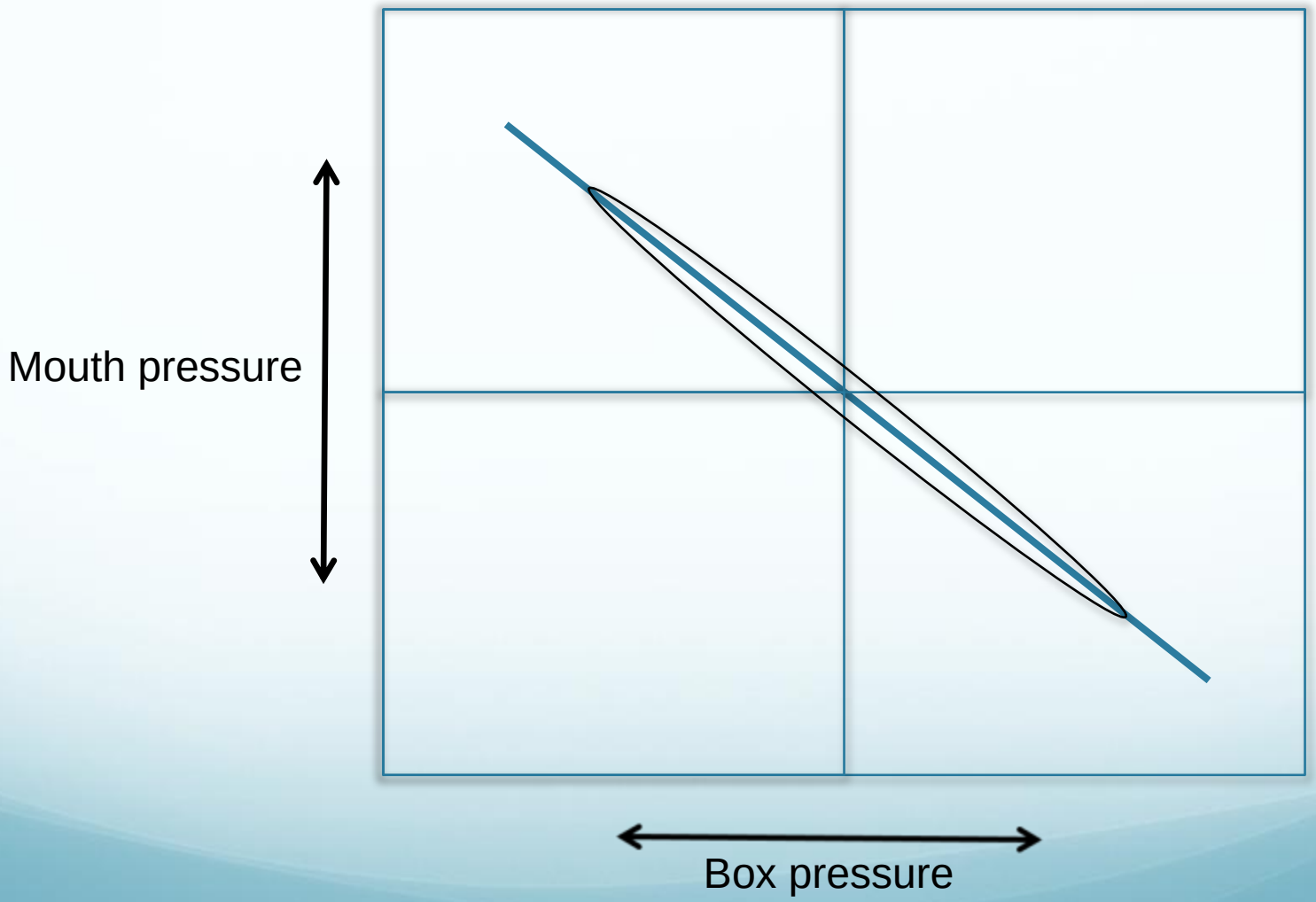


Know your angles

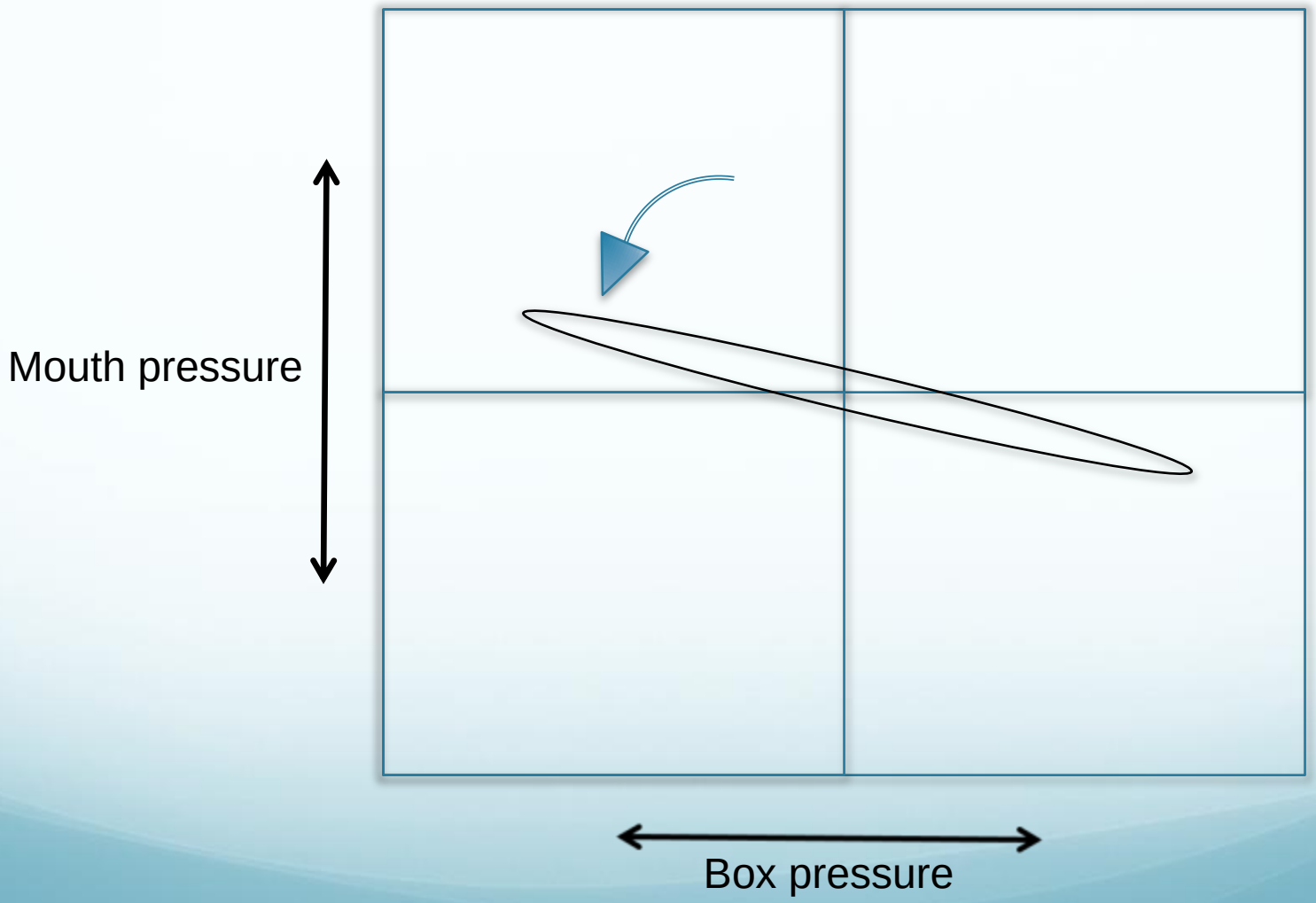
Computer generated line plots must be verified and adjusted by operator

- Closed loops
- Recognize and exclude artifact or efforts out of range.
- Minimal hysteresis

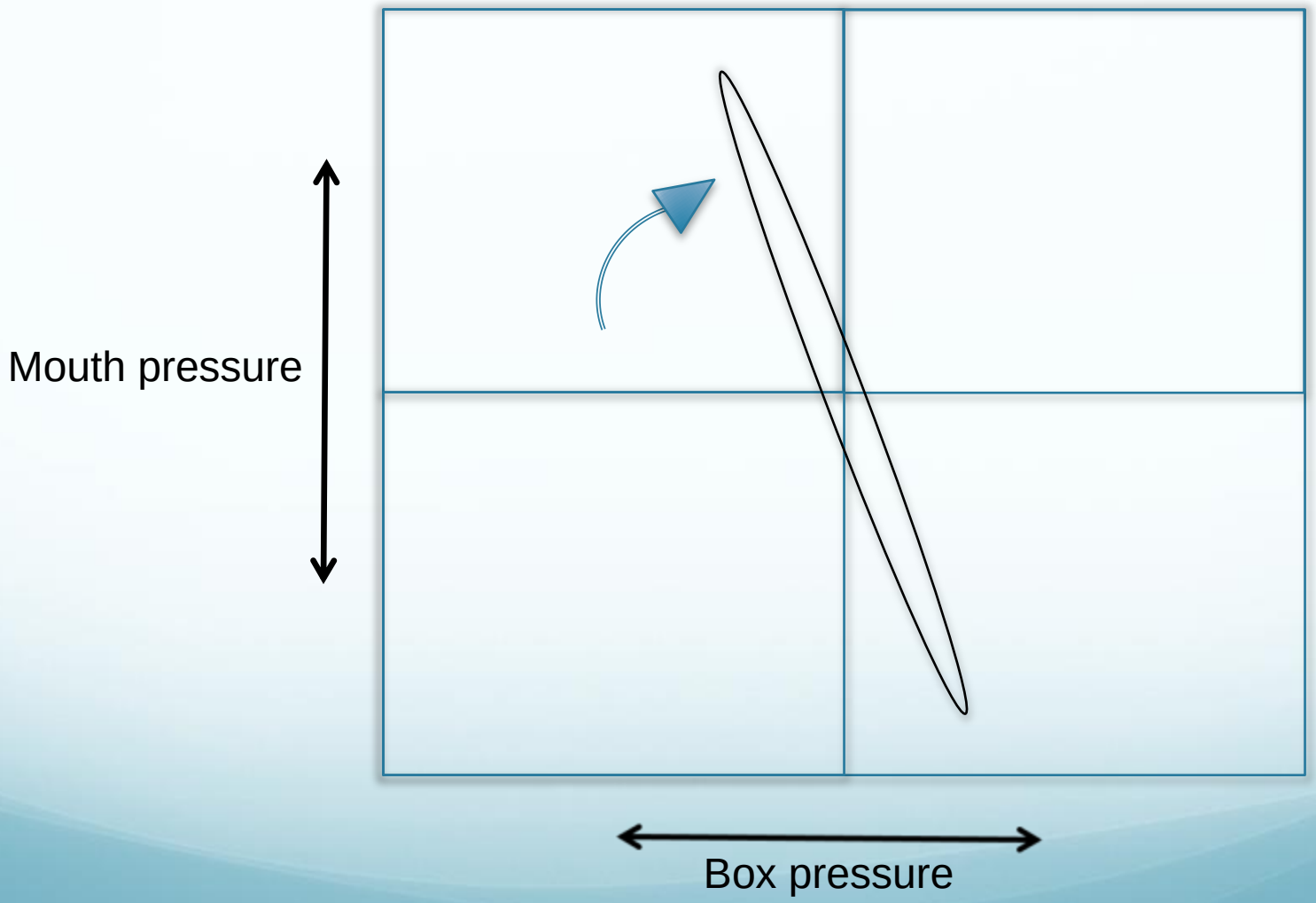
FRC (TGV) by plethsymography



Greater compressible volume



Smaller compressible volume



Repeatability

- 3-5 acceptable trials
- FRC within 5%
- Compare SVC with FVC. If SVC is smaller identify cause
- VA < TLC (within 500 mls). VA can be much smaller in advanced obstruction
- TLC within 10% of largest acceptable
- RV with 10% of lowest acceptable

Reporting

Measure: VC, TGV (at FRC), IC, ERV

- FRC obtained from separate TGV measurements. Avoid TGV from RAW: wrong frequency and likely volume above resting FRC
- Obtain 3 -5 acceptable occluded panting cycles (each cycle includes 3-5 panting angles)
- Minimize switch-in error

Calculate: TLC, RV

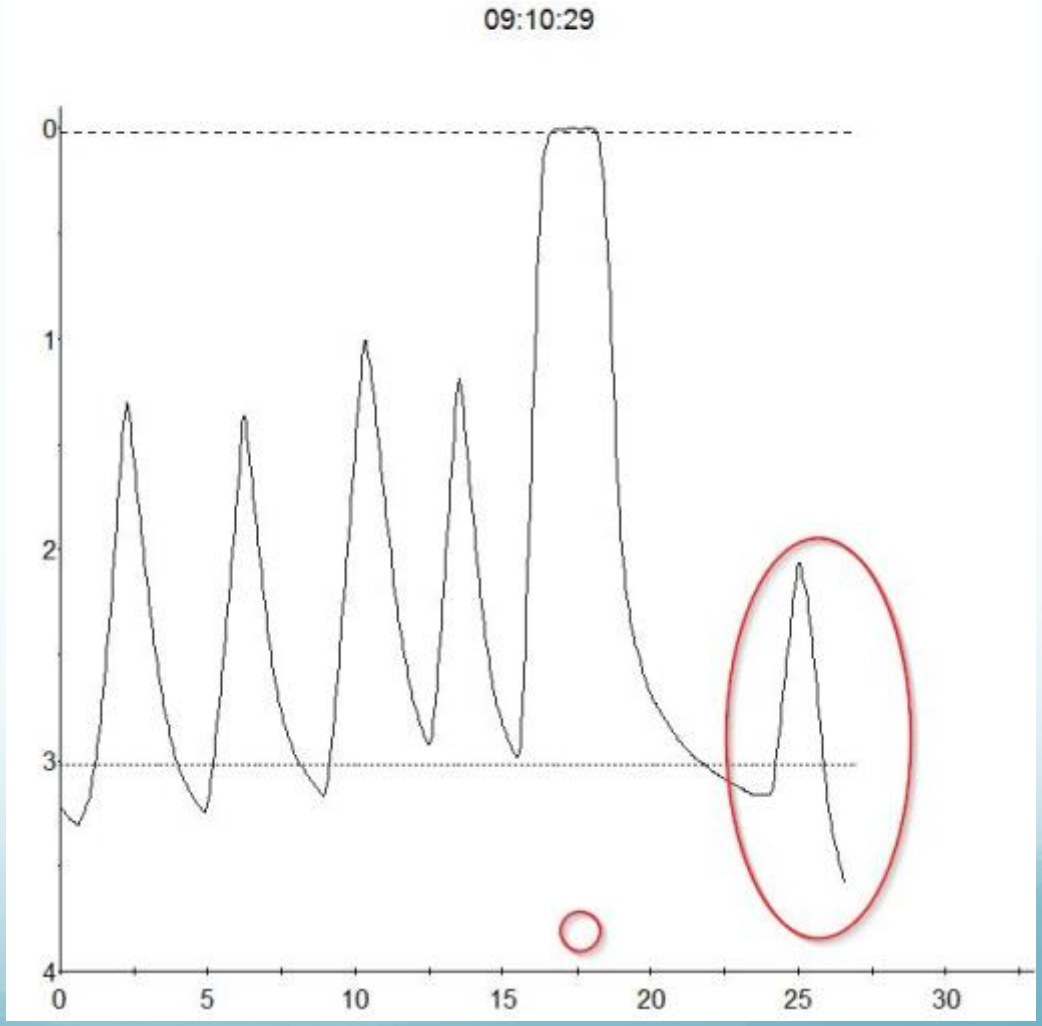
- Average TGV, IC, ERV used for TLC calculation from the described ATS/ERS Lung Volumes standards
- May depend on which method used for testing (linked or non linked IC, SVC)
- Best VC reported

Measurement errors:

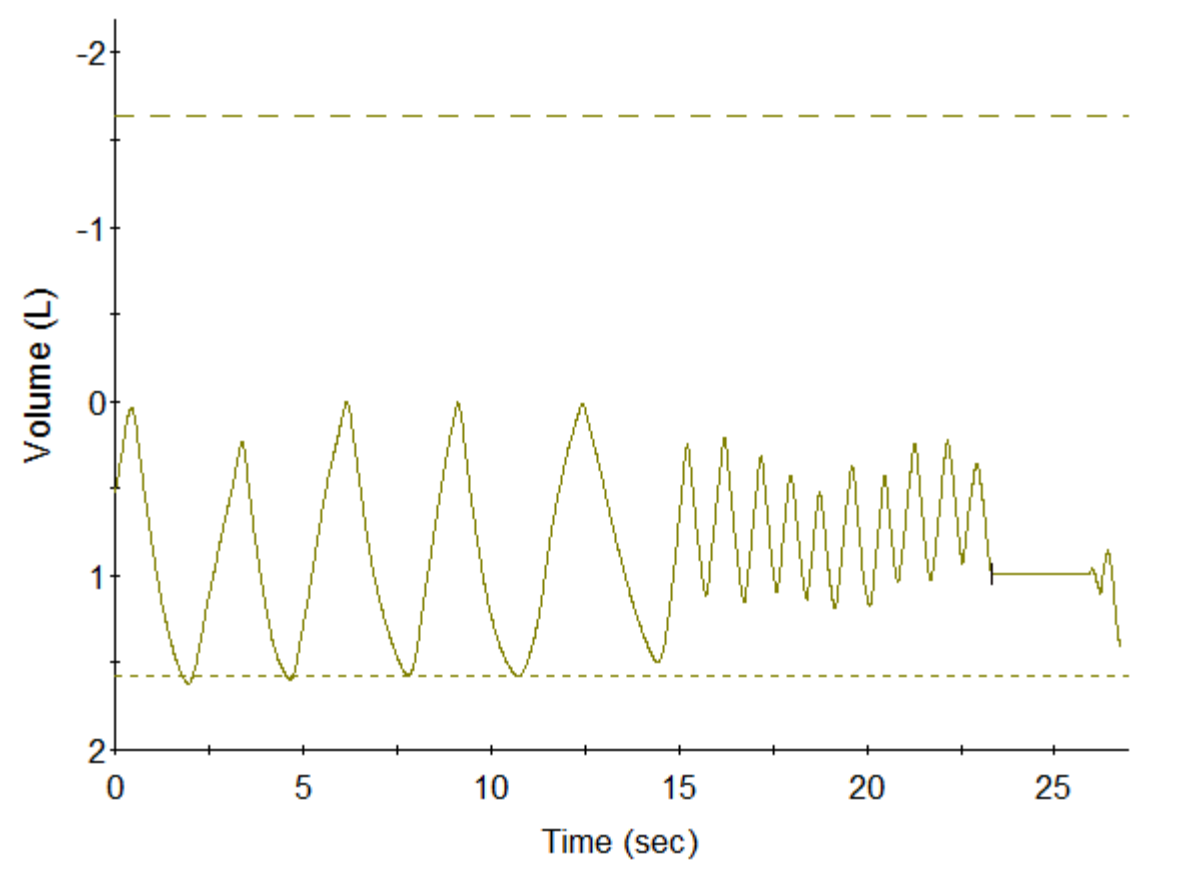
- Insufficient time for thermal equilibrium
- Panting frequency, depth, position, work of breathing
- May need to allow patient to recover between efforts
- Computer generated line plots must be verified and adjusted by operator
- Artifact
- Panting out of range
- Leak around mouthpiece or noseclips
- Contact with the bodybox walls
- Minimize switch in error at FRC/iTGV <100-200 mls

Disconnect near RV

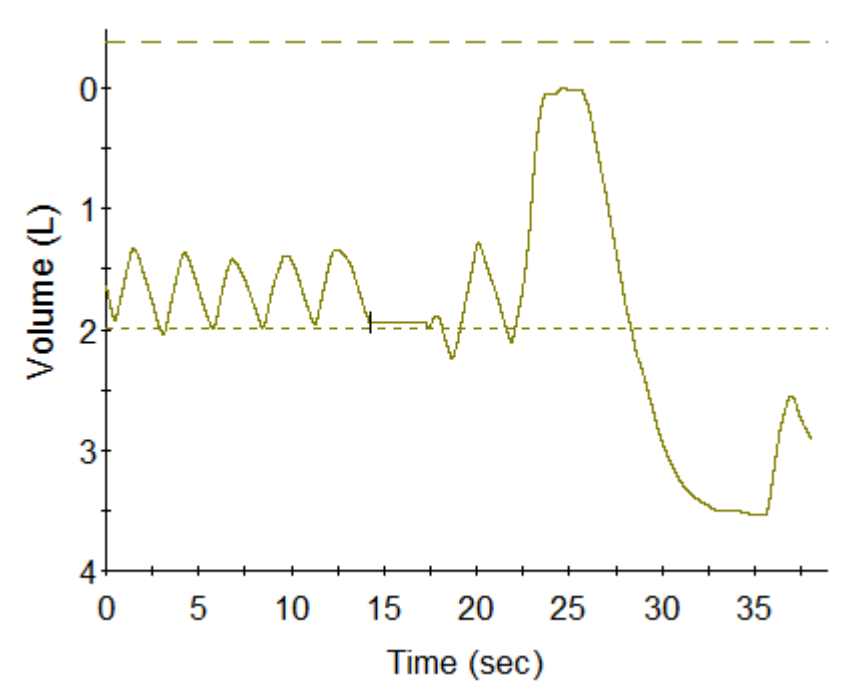
				SVC absolute	SVC % p/c	IC absolute	IC % p/c	ERV absolute	ERV % p/c
				4.20		3.77		0.43	
			SVC	3.59	85	3.02	80	0.57	131
			SVC	3.17	75	2.87	75	0.31	71
			SVC	3.32	79	3.02	80	0.30	70



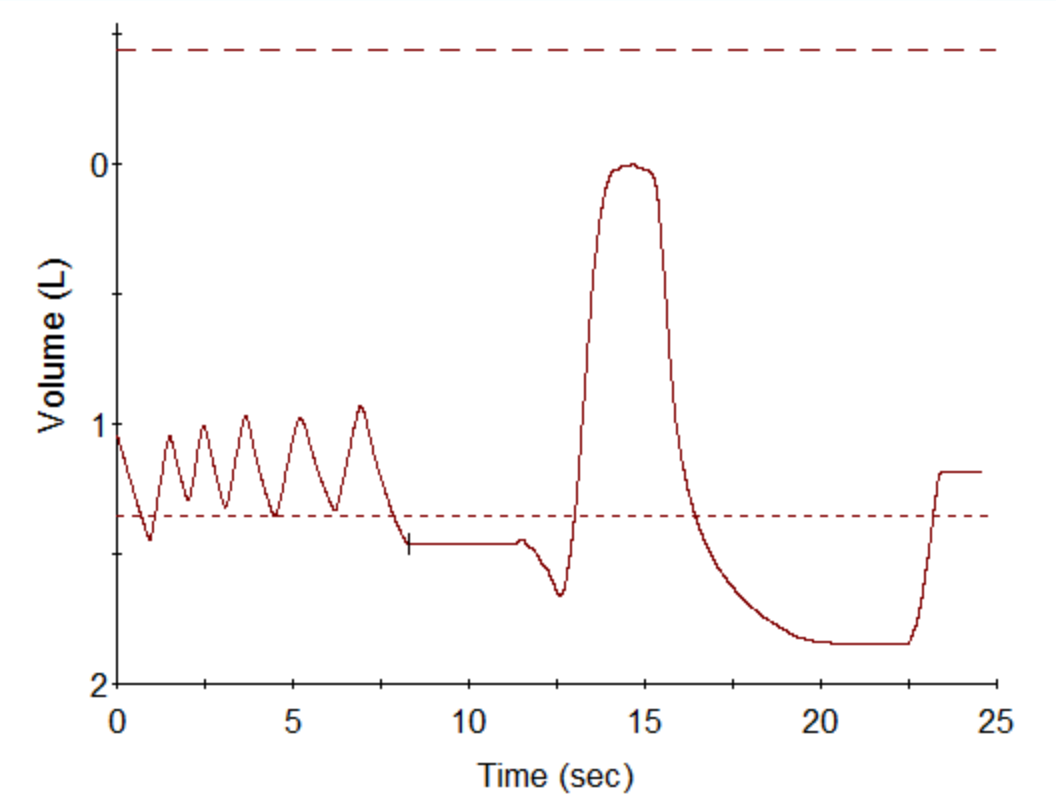
Elevated FRC point during RAW



Switch in at FRC



Switch-in below FRC



Demonstration and Questions