MEASUREMENT OF LUNG VOLUMES

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MEASUREMENT OF LUNG VOLUMES

- Introduction and Definitions

- Helium-dilution technique

- N_2 washout technique

Lung Function
Two General Patterns

- Obstructive disease
  - cannot get the air out
    - airways obstruction
  - reduction of FEV_1/VC, sG_{AW} and VC (sometimes)

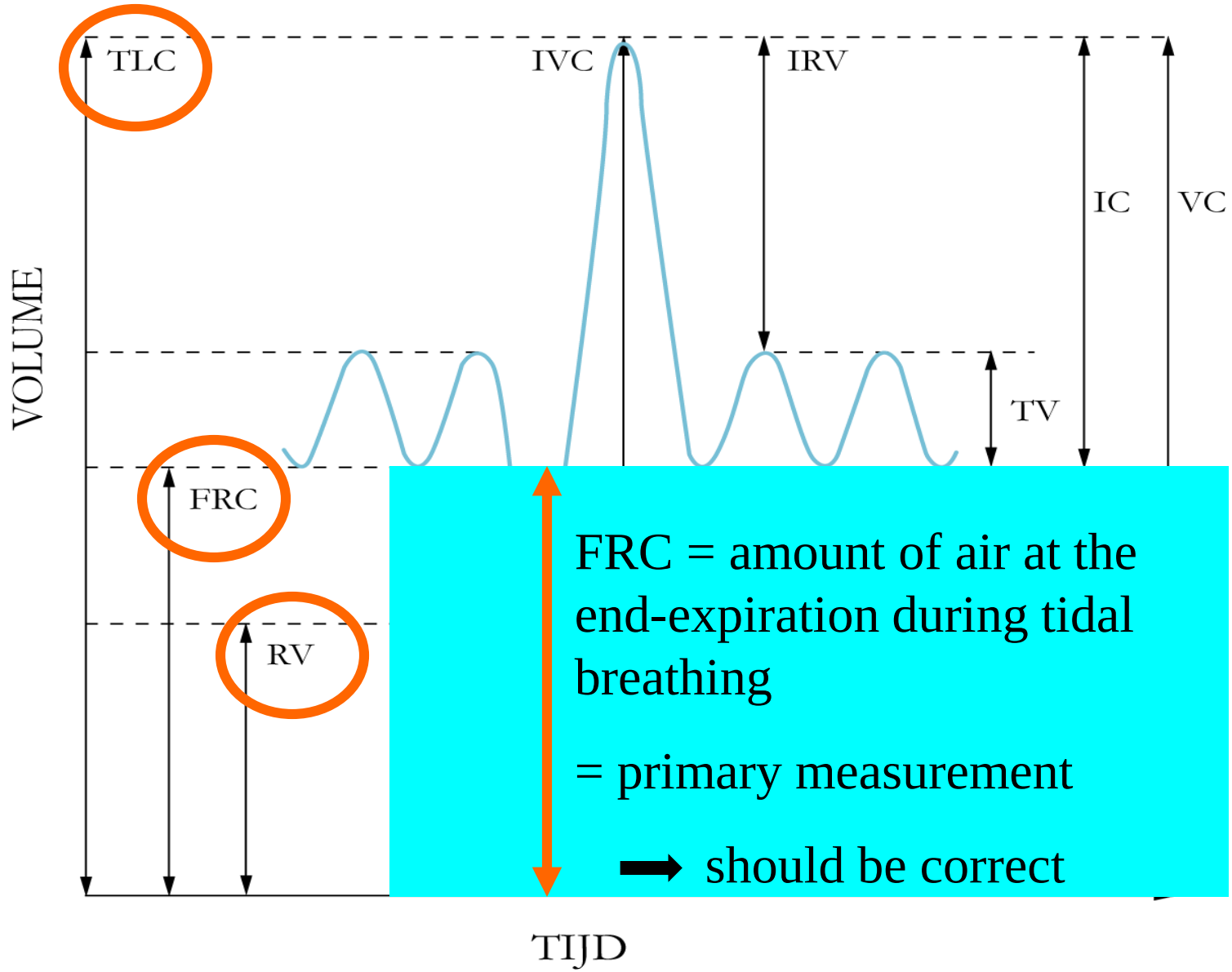
- Restrictive disease
  - cannot get the air in
    - lungs are scarred or infiltrated
    - lung tissue compressed by other tissue, fluid, heart..
    - muscles are weak
    - disorder of thoracic wall, spine...
  - reduction of TLC, and (generally) other lung volumes

Question I: *When lung volumes are measured, what is the primary measurement (starting point)?*

chose 1 answer!

1. Total lung capacity (TLC)
2. FRC (Functional Residual capacity)
3. IC (inspiratory capacity)
4. RV (residual volume)
5. ERV (espiratory reserve volume

Static Lung Volumes and Capacities

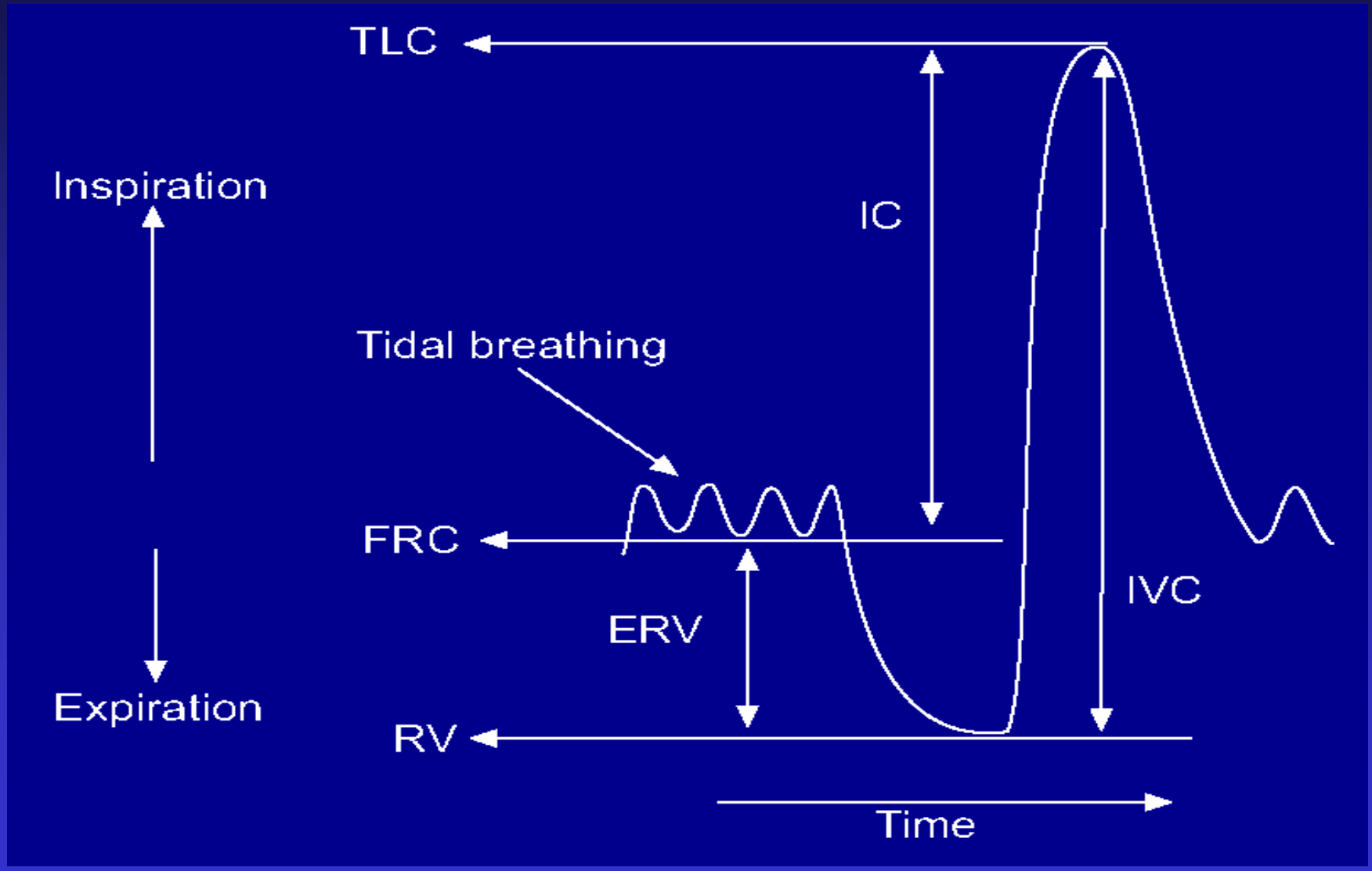


MEASUREMENTS OF RV AND TLC
Preferred Method of Calculation

Sequence

- *measure FRC*
- *then measure ERV (substract it from FRC) --> RV*
- *thereafter a slow IVC maneuver to measure TLC*
- *all performed as linked maneuvers*

MEASUREMENTS OF RV AND TLC
Preferred Method of Calculation



MEASUREMENTS OF RV AND TLC
Preferred Method of Calculation

RV value

- *RV = FRC - ERV*
- *ERV = mean of (3) technically acceptable ERV measurements*

TLC value

- *TLC = FRC + IC*
- *IC = largest of (3) technically acceptable IC measurements*

MEASUREMENTS OF RV AND TLC
Second Preferred Method of Calculation

Sequence - in patients with dyspnea/COPD

- *perform an IC measure immediately after FRC and add it to FRC --> TLC*
- *allow them to come off the mouthpiece*
- *perform then an EVC maneuver, or an ERV maneuver followed by a IVC maneuver*

Background
Techniques to Measure TLC

- Dilution Techniques
- Washout Techniques
- Compressible gas
- Imaging

- Helium (He)
  - Single breath
  - Multiple breath
- Nitrogen (N_2)
  - Single breath
  - Multiple breath
- Bodyplethysmography
- Chest X-ray and CT

Question II: *the magnitude of an FRC measurement in COPD is dependent on the method used. What is correct?*

chose 1 answer!

1. FRC He multiple breath > FRC (body-box) > FRC He single breath
2. FRC (body-box) > FRC He single breath > FRC He multiple breath
3. FRC (body-box) > FRC He multiple breath > FRC He single breath

Comments on question 2

FRC (body-box) > FRC He multiple breath > FRC He single breath

- *FRC (body-box --> trapped gas (bullae)*
- *difference between FRC He multiple breath and FRC He single breath --> ventilation inqualities*

MEASUREMENT OF LUNG VOLUMES

- Introduction and Definitions

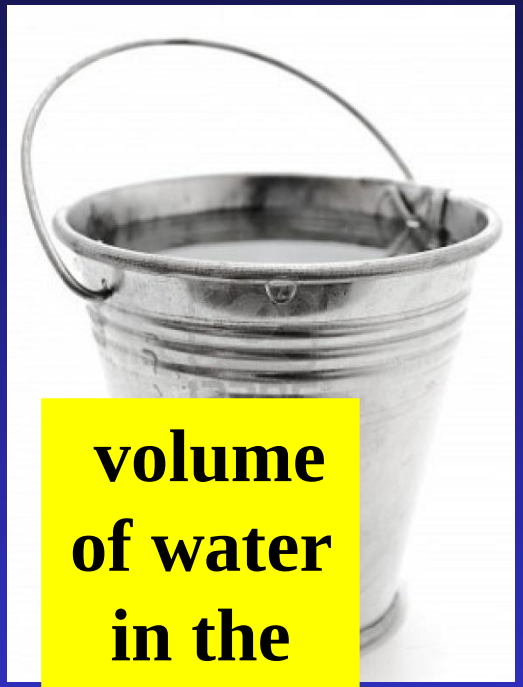
- Helium dilution technique
  - Principle of Technique
  - Equipment
  - Procedure and Calculations
  - Quality Control

- N_2 washout technique

Helium Dilution Technique Principle

To measure an unknown volume from the dilution of a known volume and concentration of a tracer gas, Helium (or another poorly soluble gas)

Helium Dilution Technique Principle



volume of water in the bucket

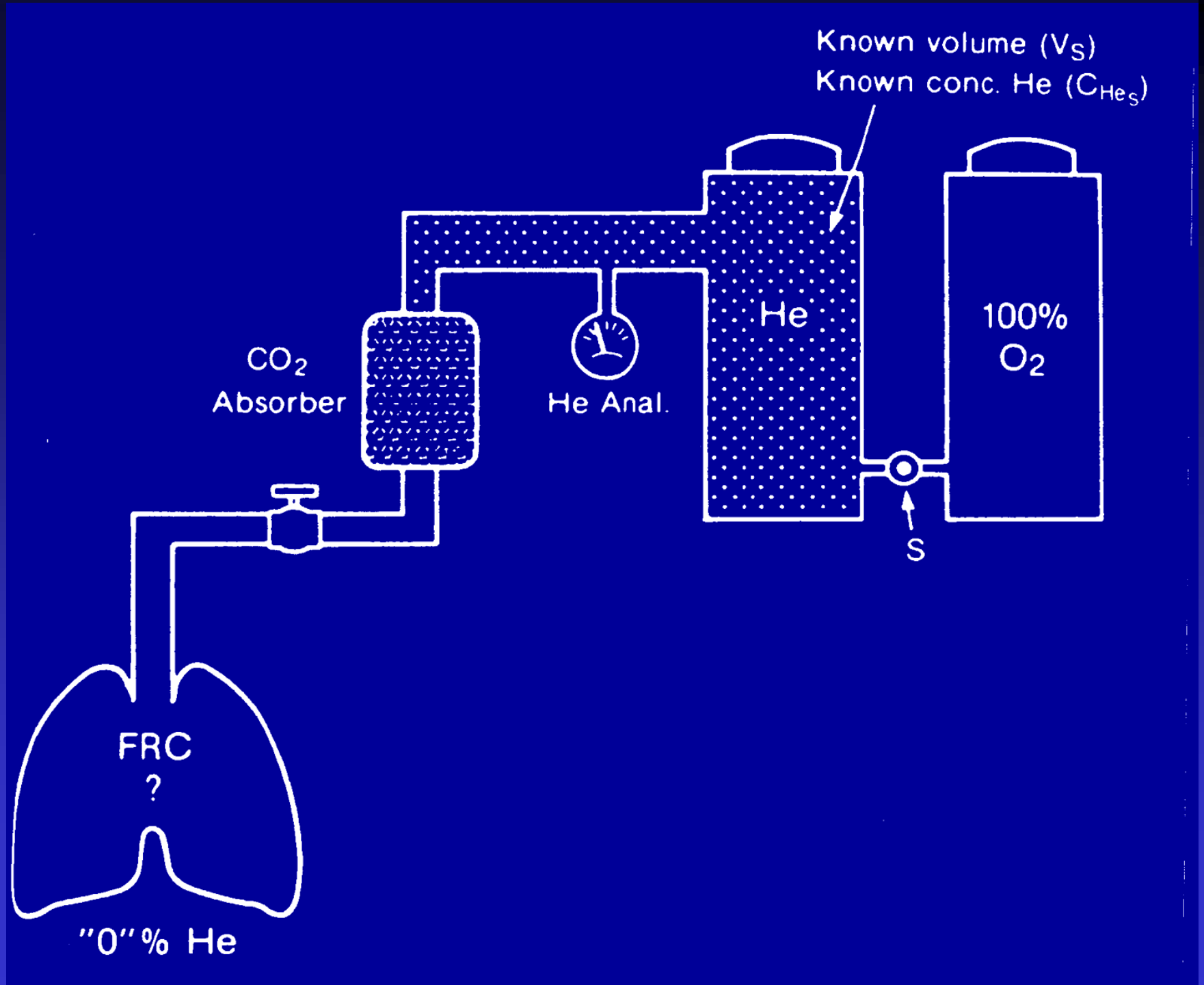
?

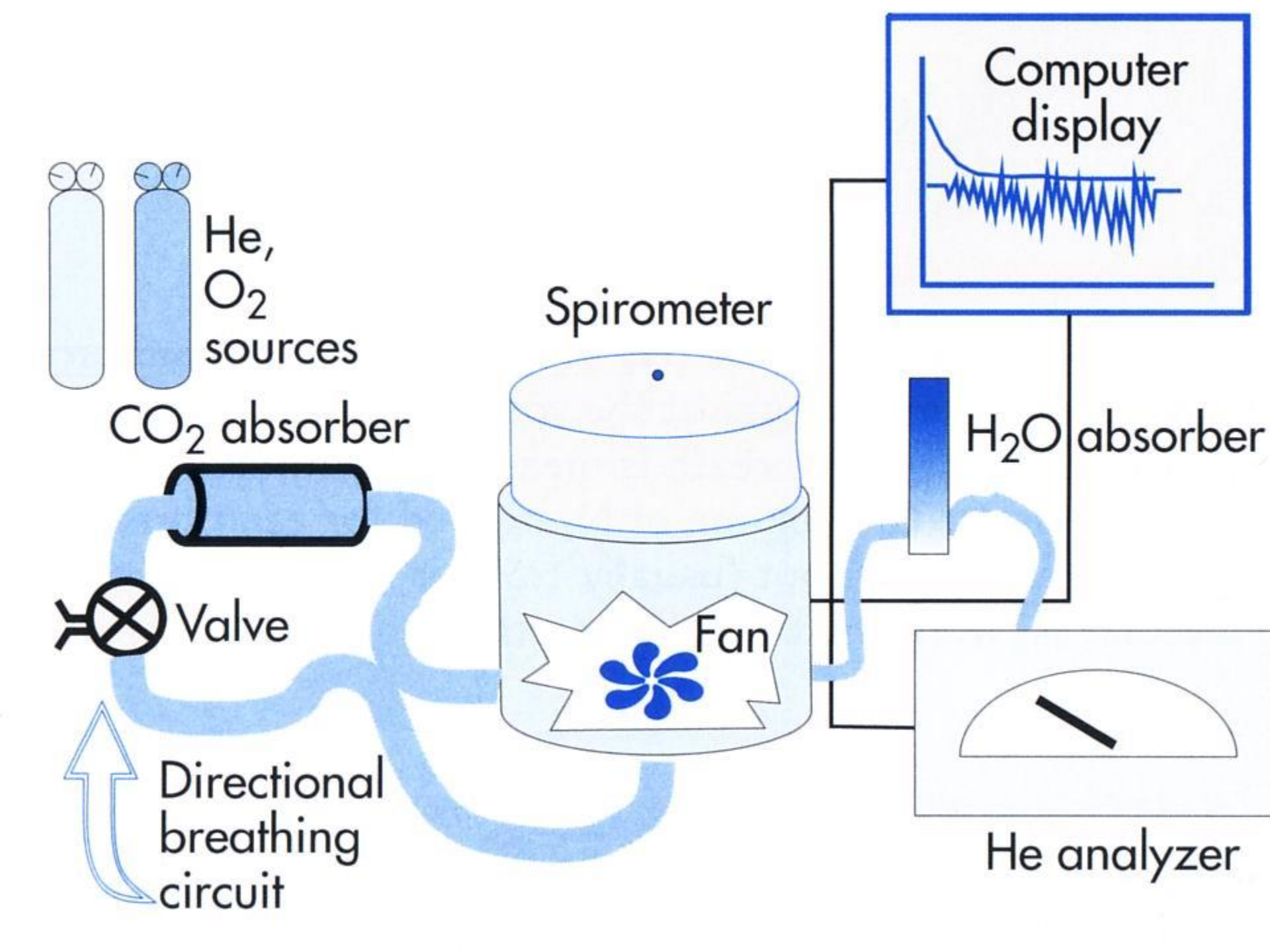
MEASUREMENTS OF LUNG VOLUMES
MULTIPLE BREATH HE DILUTION TECHNIQUE

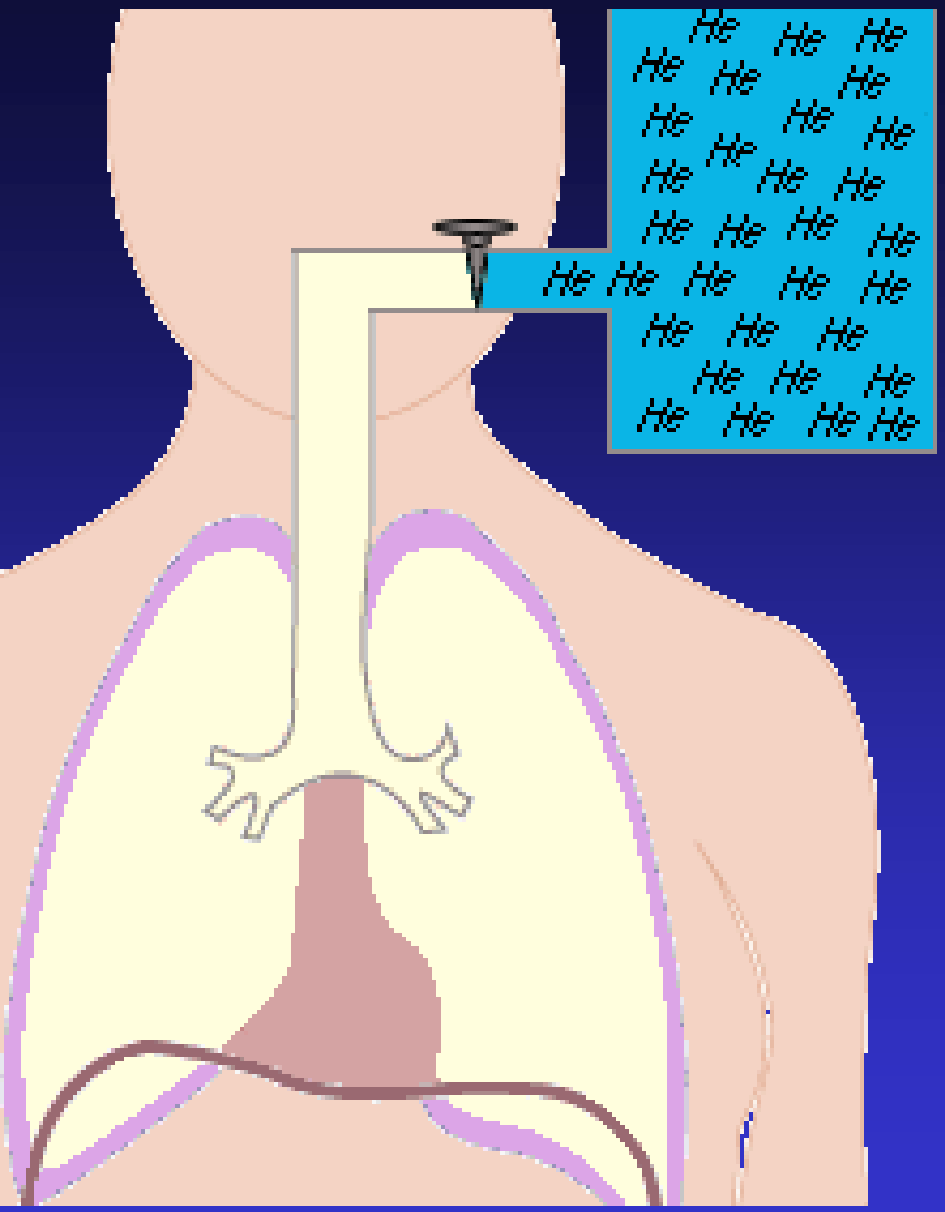
Closed-Circuit Helium Dilution:

- patient is connected to a spirometer
- CO_2 is absorbed by soda lime
- O_2 is added to replace the subject's oxygen consumption

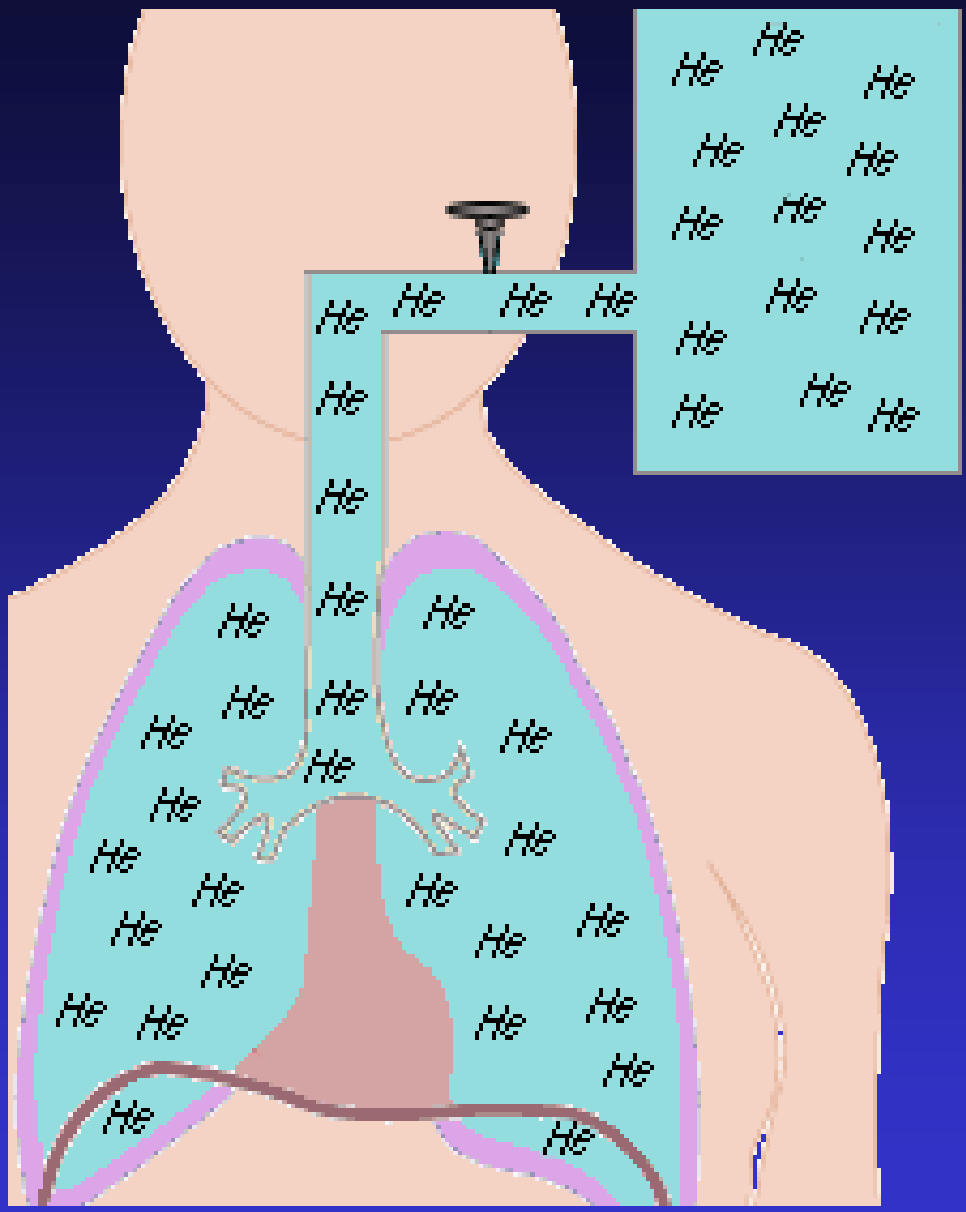
- Test gas
  - air
  - added O_2 (25-30%)
  - He (10%)


Known volume (V_S)
Known conc. He (C_{He_S})
CO_2 Absorber
He Anal.
He
100% O_2
S
FRC
?
"0" % He

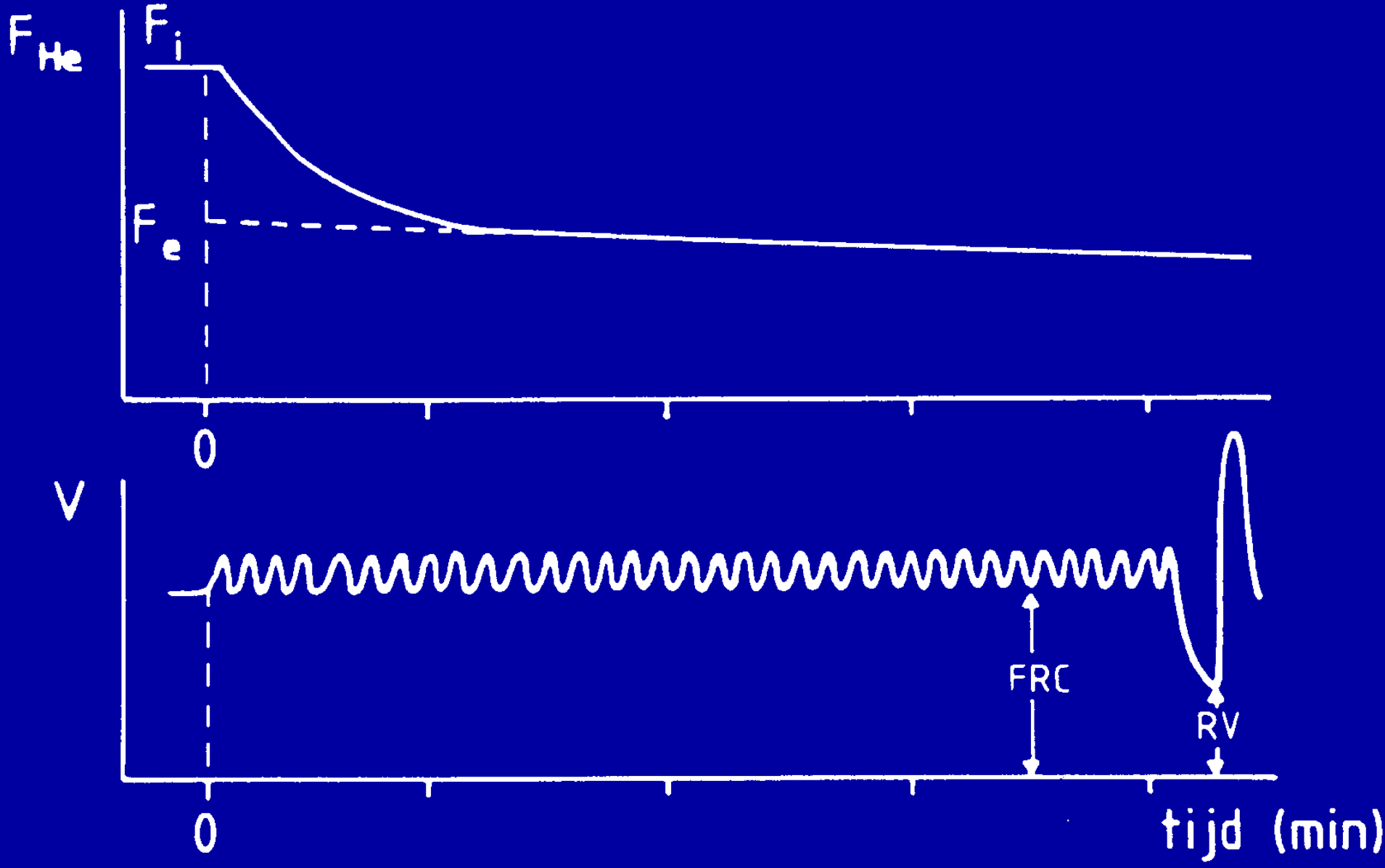

Computer display
He, O_2 sources
Spirometer
CO_2 absorber
H_2O absorber
Valve
Fan
Directional breathing circuit
He analyzer



Beginning of dilution test



End of dilution test


F_{He}
F_i
F_e
0
V
FRC
RV
0
tijd (min)

Helium Dilution Technique Principle

Initial amount of He = Final amount of He

– *closed system*

$$[He]_I \times V_s = [He]_F \times V_F$$

$$V_F = V_s + V_{TUB} + V_L$$

$$V_L = V_F - V_s - V_{TUB}$$

$$FRC = \frac{[He]_I \times V_s}{[He]_F} - V_s - V_{TUB}$$

Helium-Dilution Technique

- Principle of technique
- Equipment
- Procedures and calculations
- Quality control

Helium-Dilution Technique
Equipment III

- Helium concentration is measured every 15 sec

- Characteristics of He-analyzer
  - range 0-10%
  - resolution $\leq$ 0.01%
  - 95% response time $\leq$ 15 sec to a Δ 2% in He concentration
  - drift $\leq$ 0.02% for up to 10 min

Helium-Dilution Technique

- Principle of technique
- Equipment
- Procedures and calculations
- Quality control

Helium-Dilution Technique
Procedure and Calculations III

- Ask about perforated eardrum ---) earplug
- Patient is seated, wearing a nose clip
- Patient is connected to mouthpiece breathing quietly for 30 - 60 sec
- **Wait for stable end-tidal expiratory level**
- Switch the valve and connect the patient to the closed system at the end of a normal expiration

Helium-Dilution Technique
Procedure and Calculations V

- Note Helium concentration during equilibration every 15 sec

- Gas mixing is complete when
  - Helium concentration < 0.02% for 30 sec
    = the increase in FRC of 80 ml/min

- *resolution of Helium meter* ≤ 0.01%
- = 0.01% Helium/min ->*increase in FRC by 20 ml/min*

Helium-Dilution Technique
Procedure and Calculations VI

- Criteria for end of testing
  - *the decrement in He concentration < 0.02% in 30 sec*

  or

  - *change in FRC < 40 ml in 30 sec*
- Procedure rarely exceeds 10 min

Helium Dilution Technique
Duplicate Analysis

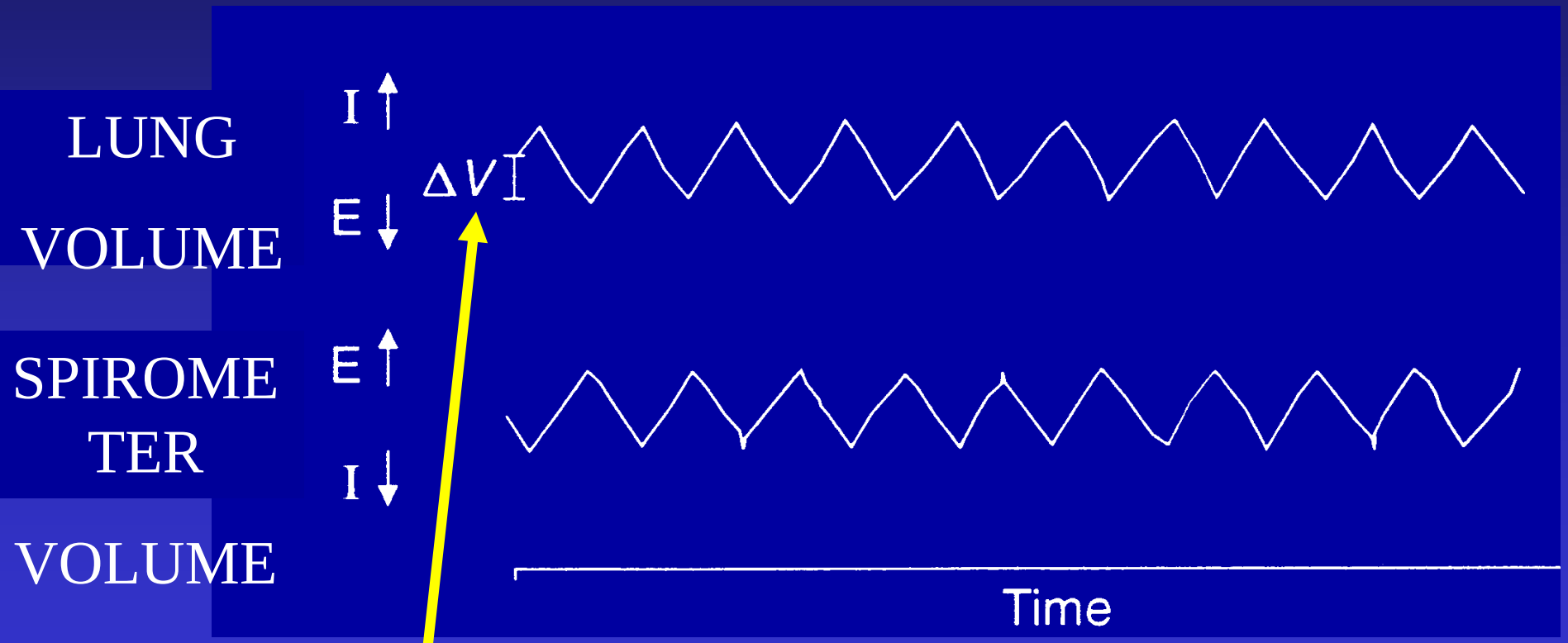
- Coefficient of variation for FRC
  - 5% in normal subjects
  - 6% in COPD patients
  - 95% C.I. ± 400 ml
  - 85% within 200 ml
- Single measurement, unless special circumstances
- 3 measurements, if two tests do not agree within 200 ml
- 5 to 8 [10 - 20] min between measurements

Helium Loss
----) leads to overestimation of FRC

- absorption of Helium into the body
  - *no corrections*
- excretion of N_2
  - *no corrections*
- equipment leaks
  - -> *check before test*
- swallowing - leaks around nose clip/mouthpiece
  - -> *be attentive*
- ruptured tympanic membranes
  - -> *ask the patient*

Helium Dilution Technique
Switching Error

- Patient is not always switched exactly at end-expiratory level



- Correction should be made

Helium Dilution Technique
Changes in Lung Volume

- Patient is sometimes encouraged to take intermittent deep inhalations
  - not recommended in patients with airways obstruction, because:
    - it may take several breaths to return to the original FRC
    - it may cause errors in addition of O_2

Helium Dilution Technique

- Principle of technique
- Equipment
- Procedures and calculations
- Quality control

Helium Dilution Technique
Quality Control

- After each measurement
  - Inspection of volume-time tracings
    - switch-in and switch-out volume > 300 ml suggests leaks
  - Mention time for equilibration for each patient

Question III: *What kind of information does an increased time for equilibration in a COPD give you*

chose 1 answer!

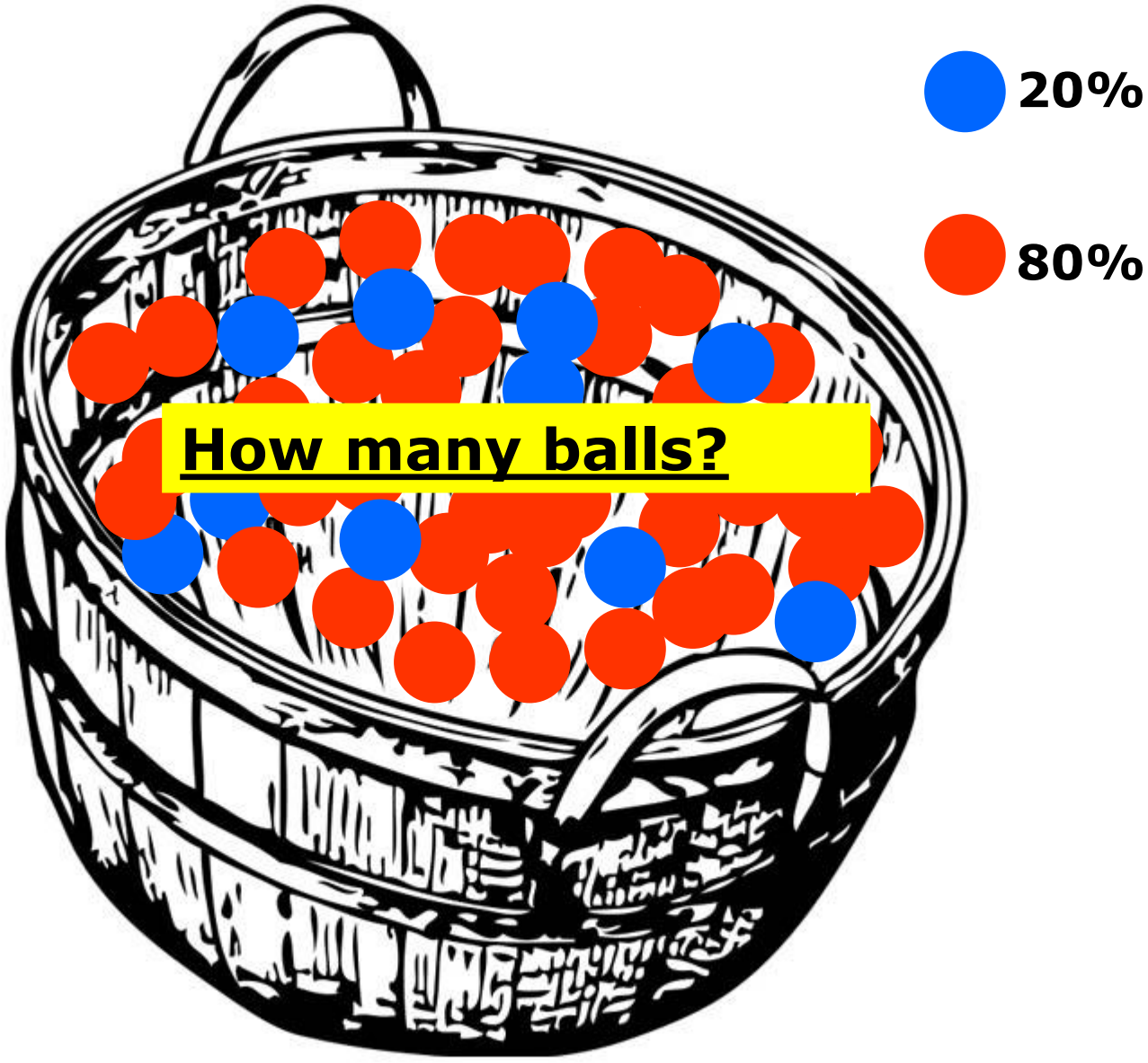
1. Increased dead space
2. Ventilation inequalities
3. Trapped gas

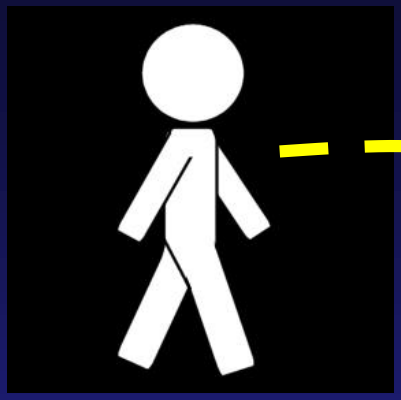
MEASUREMENT OF LUNG VOLUMES

- Introduction and Definitions
- Helium dilution technique
- N_2 washout technique
  - Principle of Technique
  - Equipment
  - Procedure and Calculations
  - Quality Control

Nitrogen Washout Technique Principle

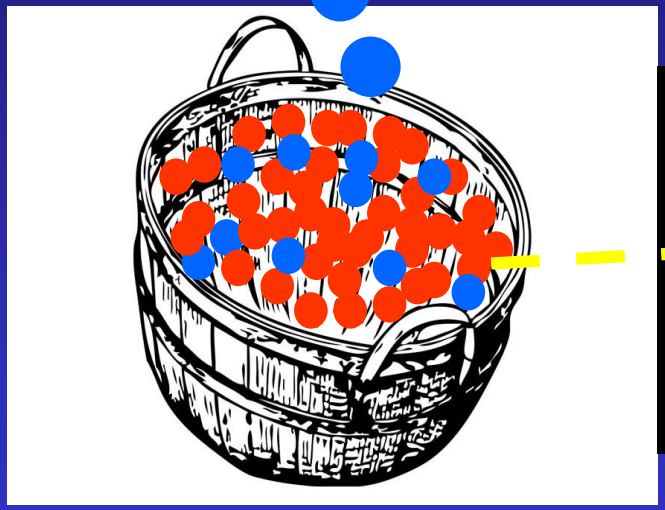
To measure an unknown volume from the washout of a known volume and concentration of a nitrogen

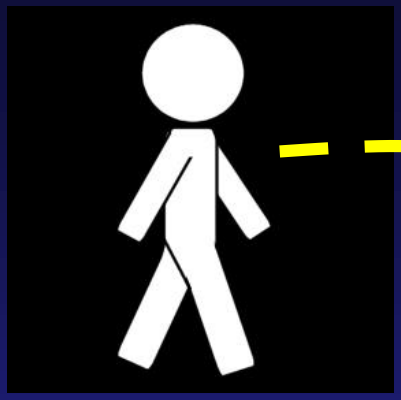

20%
80%
How many balls?



How many balls?

Red balls = 80% total amount





How many balls?

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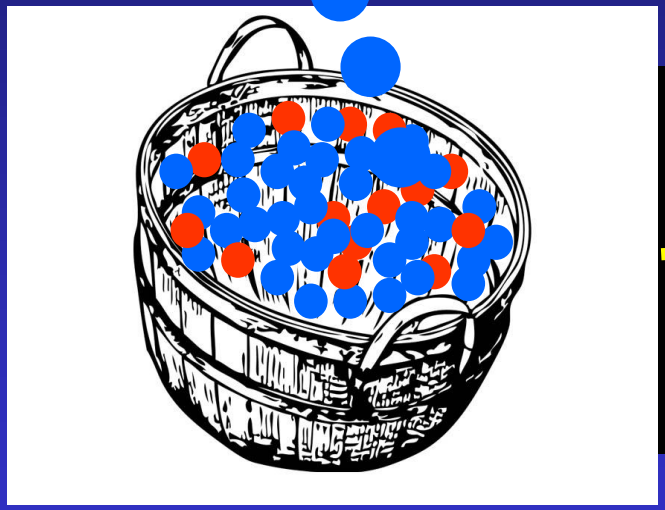
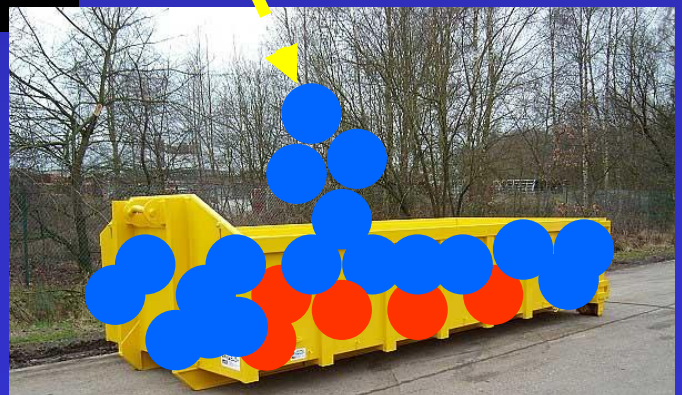
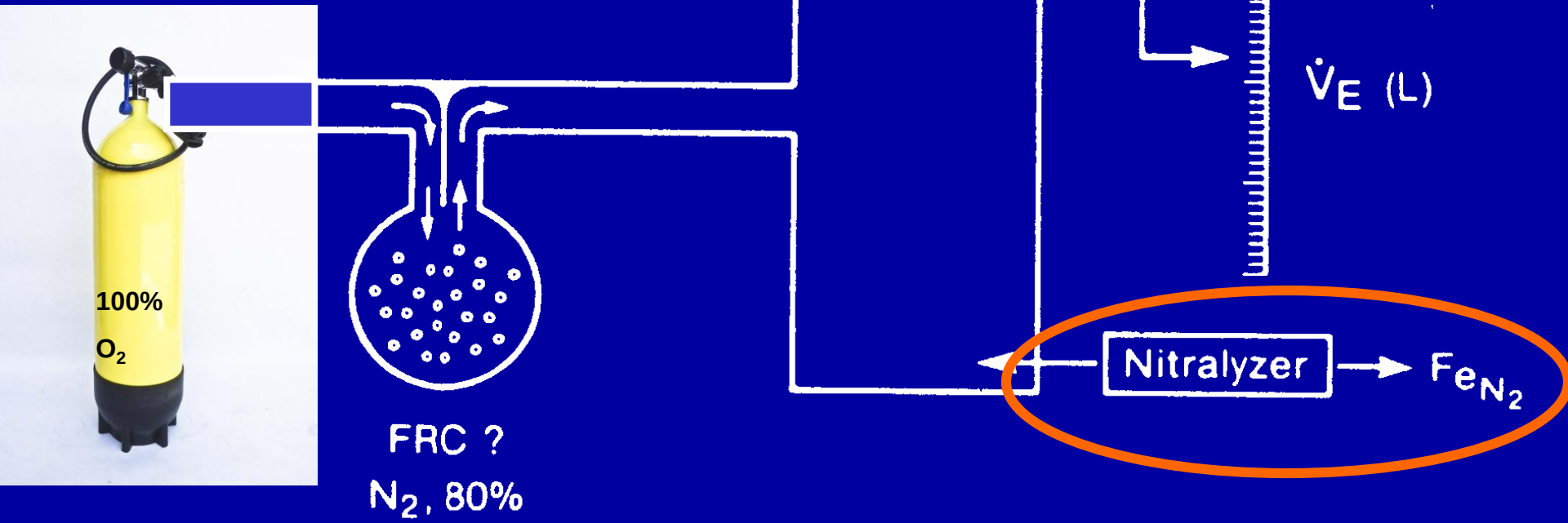


at random



Nitrogen Washout Technique Principle of Closed Circuit Method

- patient connected to a spirometer, inhales 100% O_2 during inspiration
- the expired volume of air is collected in a large bag or Tissot spirometer (± 120 L)
- lung volume is derived from expired volume and N_2 concentration in the large bag


100%
O_2
FRC ?
N_2, 80%
$\dot{V}_E$ (L)
Nitralyzer
Fe_{N_2}

Nitrogen Washout Technique
Principle of Closed Circuit Method

Initial amount of N_2 in lung = Final amount of N_2 in bag

$[N_2]_I = 0.80 \rightarrow N_2$ in lung $= 0.80 \times V_L = [N_2]_F \times V_b$

$$FRC = V_L = \frac{[N_2]_F \times V_b}{0.80}$$

Remarks:

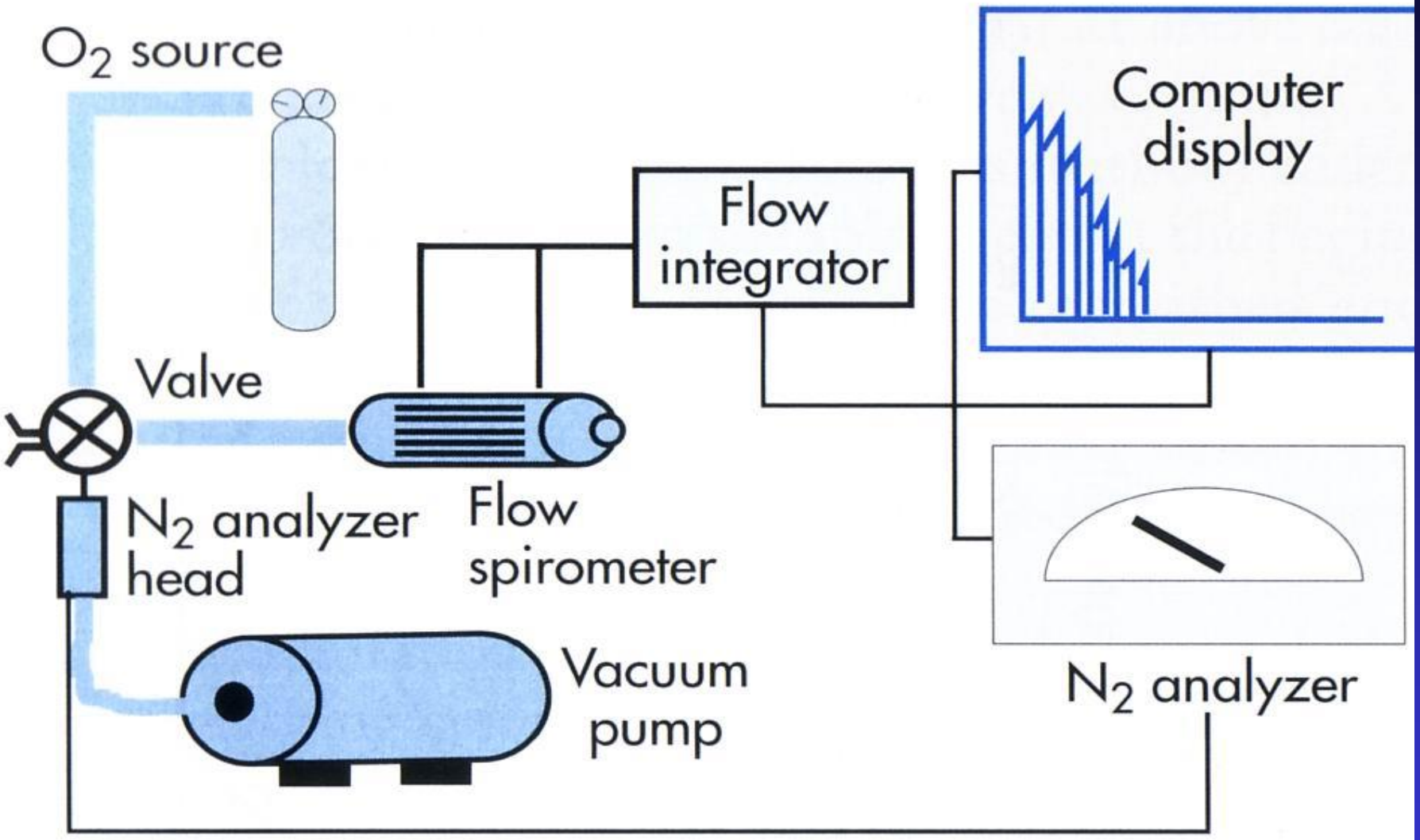
- $[N_2]_F > 0$
- N_2 stores in tissue: ± 220 ml = ((BSA x 96.5) + 35)/08 ml)

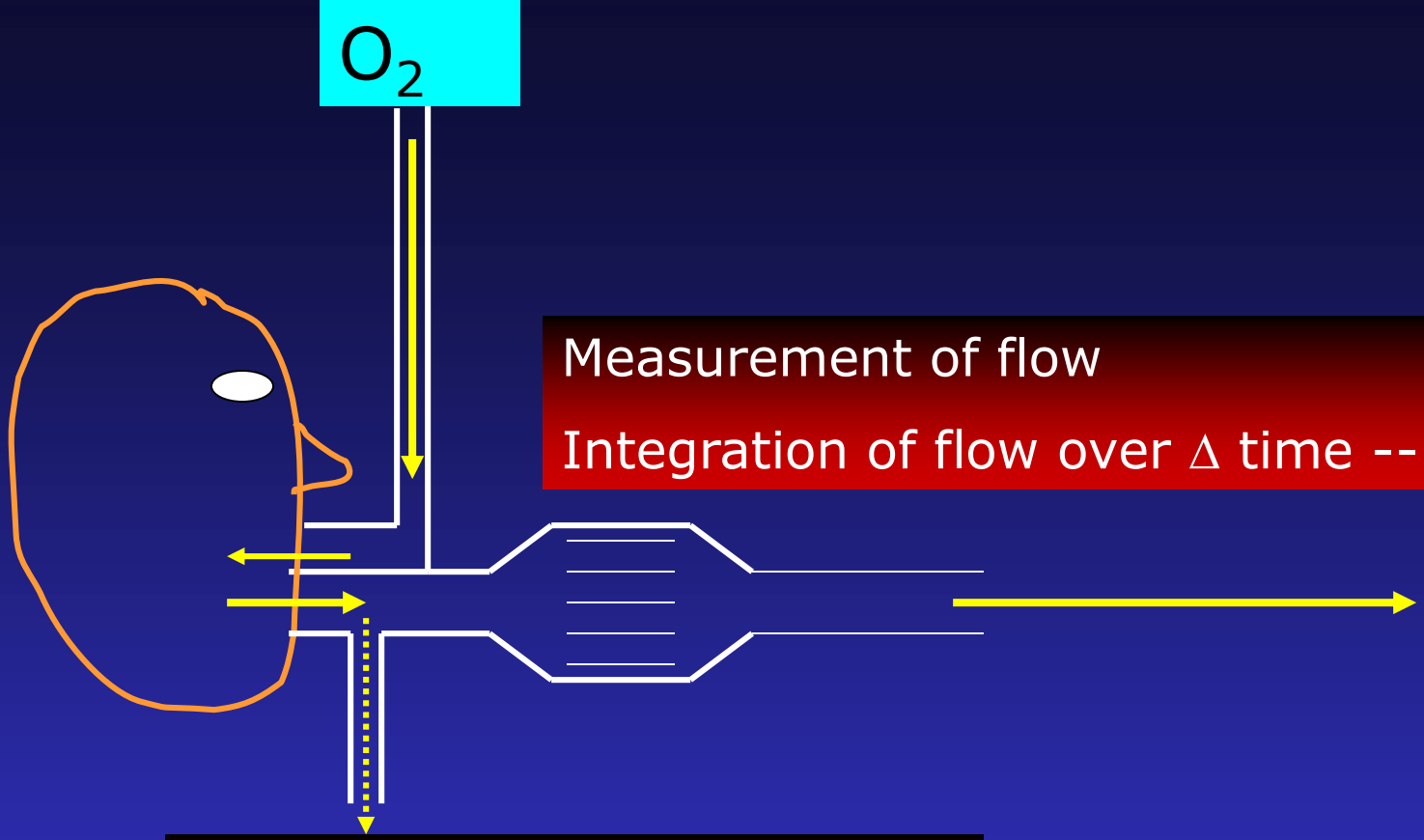
- $$FRC = \frac{[N_2]F \times V_b - 220 \text{ ml}}{[N_2]I - [N_2]F}$$

Nitrogen Washout Technique Methodology

- **Gas collection method**
  - *$[N_2]_F$ might be very low*
  - *Inaccuracy in determining $[N_2]_F$*
  - *Inaccuracy in determining bag volume*

- **Open circuit methods**
  - *Immediate analysis of expired gas*
  - *Frequent gas analysis and flow sampling*
  - *Real time data processing*
  - *Integration of data*


O_2 source
Computer display
Flow integrator
Valve
N_2 analyzer head
Flow spirometer
Vacuum pump
N_2 analyzer



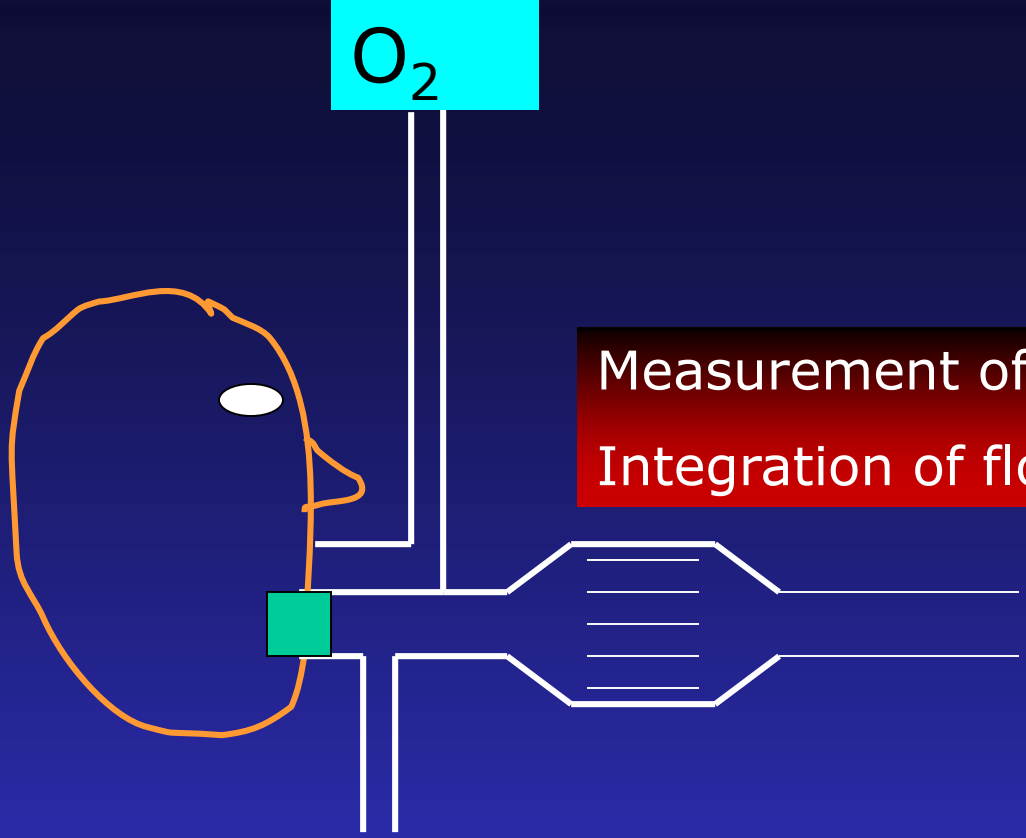
Measurement of flow

Integration of flow over Δ time --> volume

Continous sampling

On-line measurement of N_2 fraction

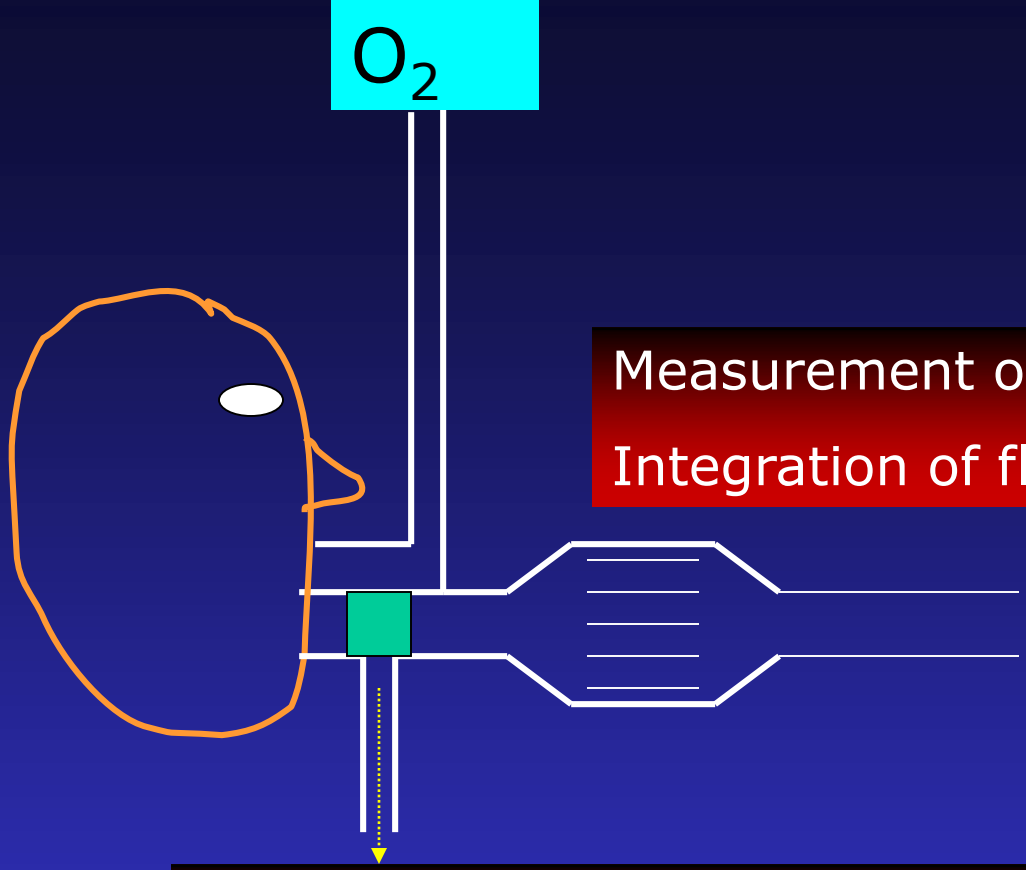
> 40 samples/sec



Measurement of flow

Integration of flow over Δ time --> volume

Measurement of N_2 fraction

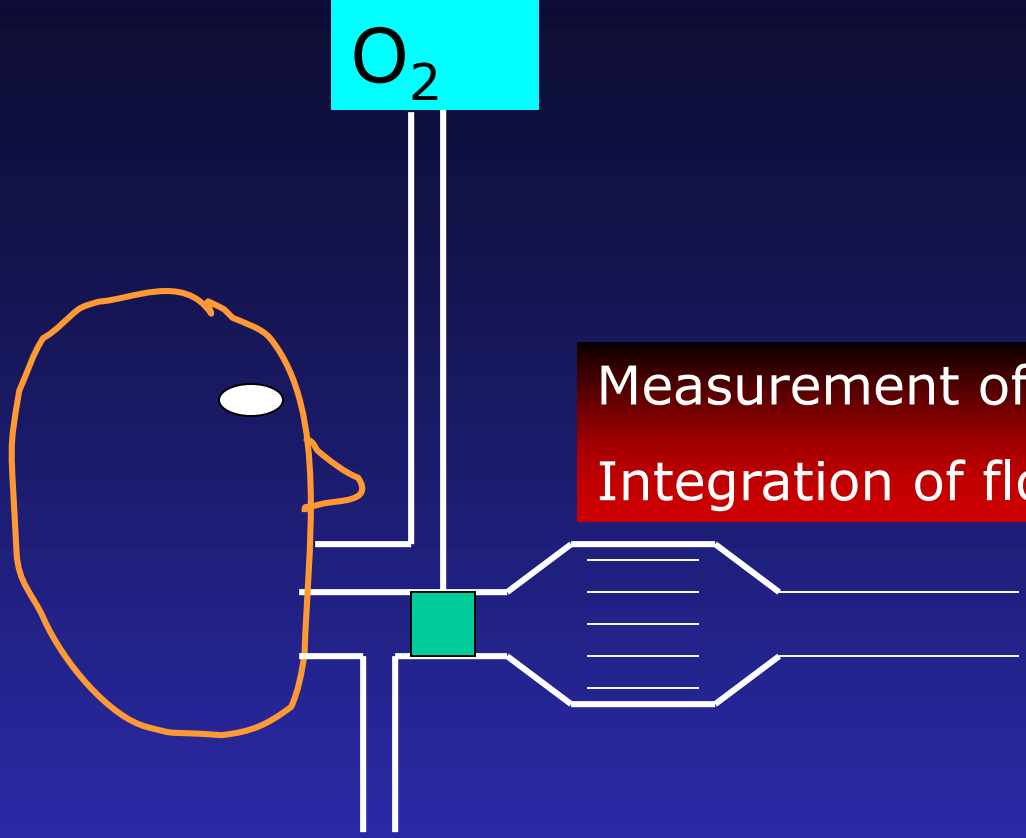


Measurement of flow

Integration of flow over Δ time --> volume

Measurement of N_2 fraction (over 25 msec)

N_2 fraction = 40%

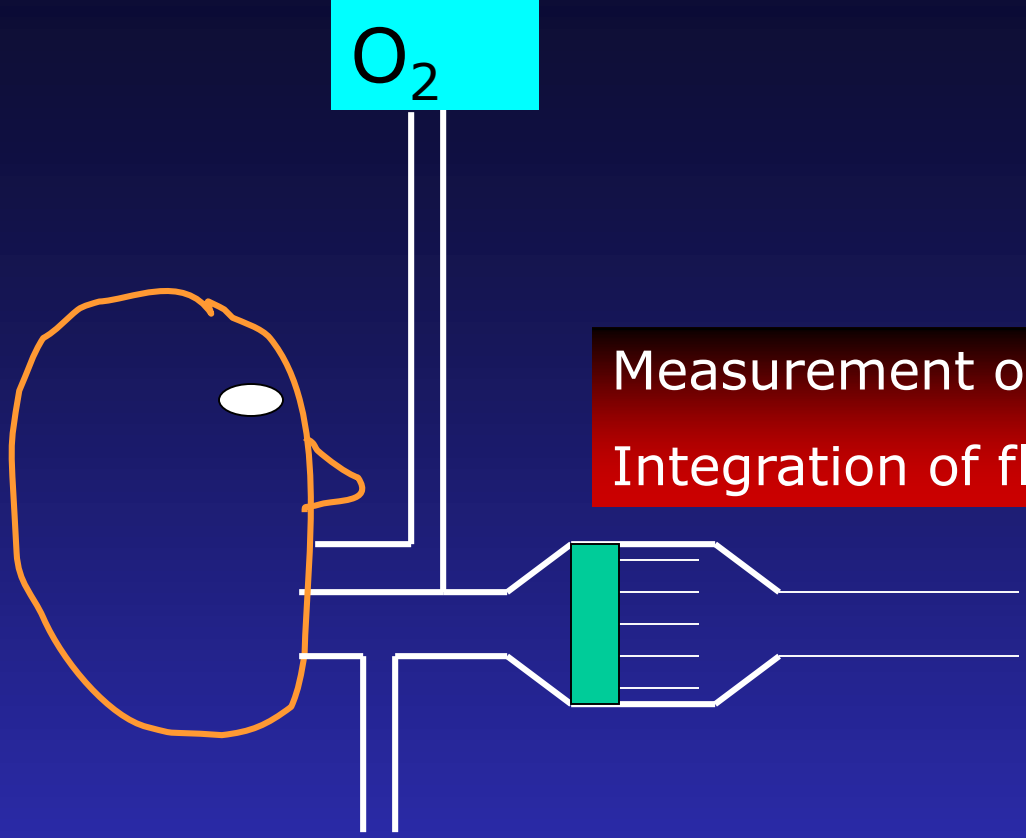


Measurement of flow

Integration of flow over Δ time --> volume

Measurement of N_2 fraction

N_2 fraction = 40%

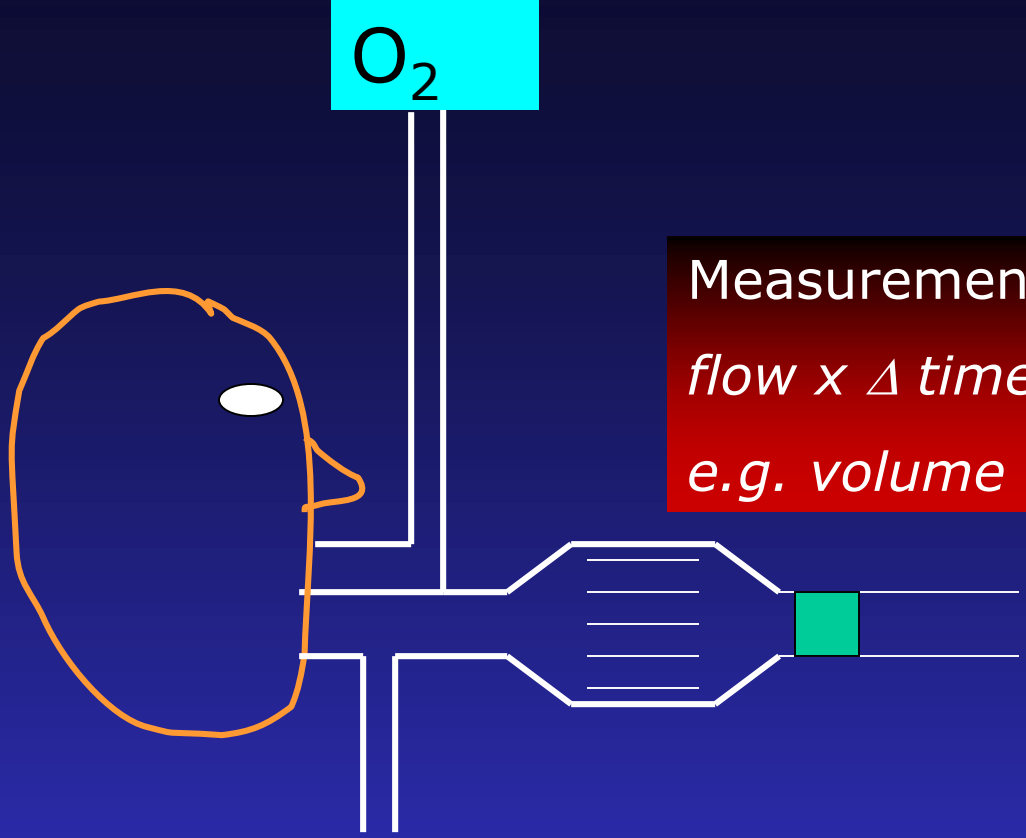


Measurement of flow

Integration of flow over Δ time --> volume

Measurement of N_2 fraction

N_2 fraction = 40%



Measurement of flow

flow x Δ time = volume

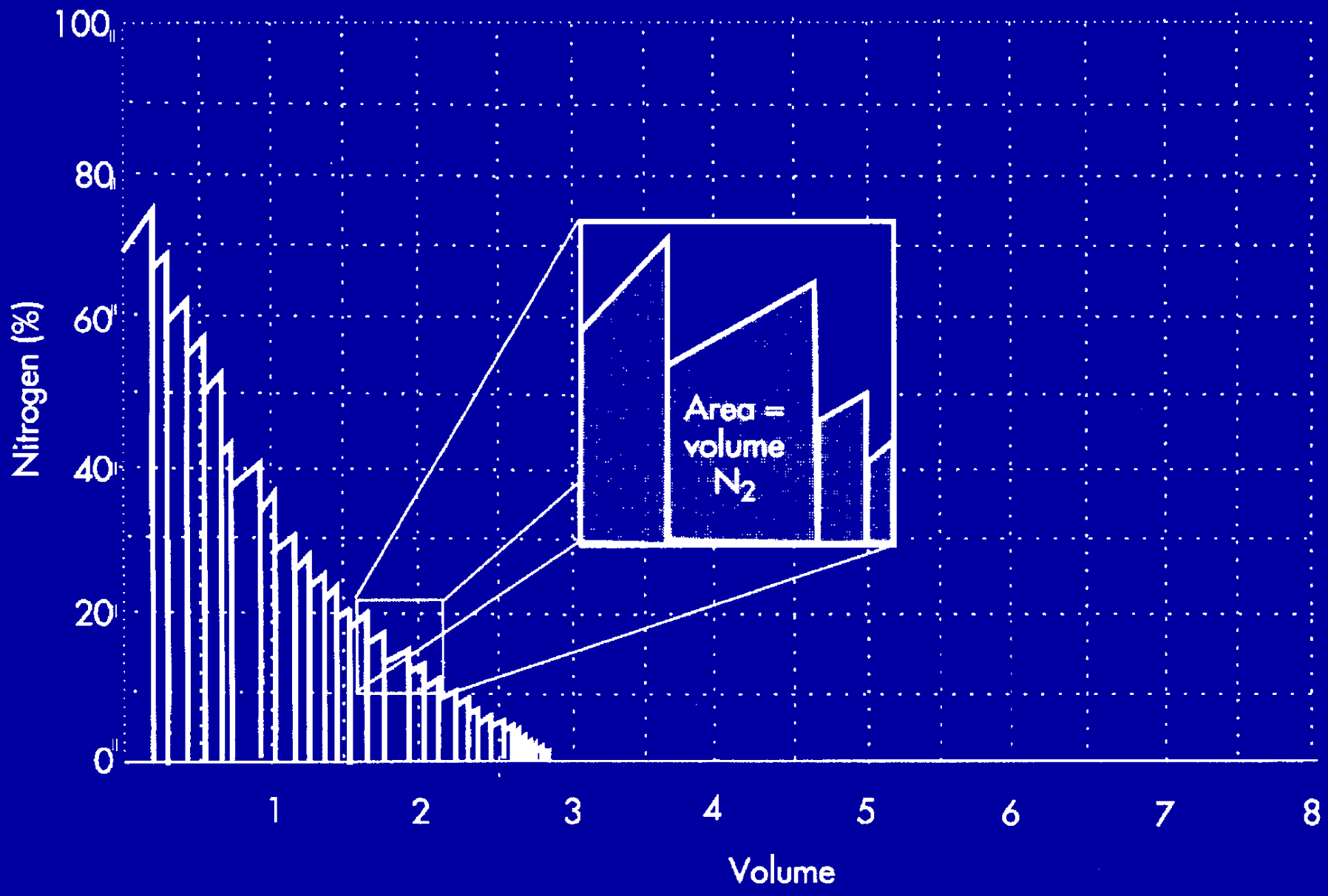
e.g. volume = 5 ml

Measurement of N_2 fraction

N_2 fraction = 40%

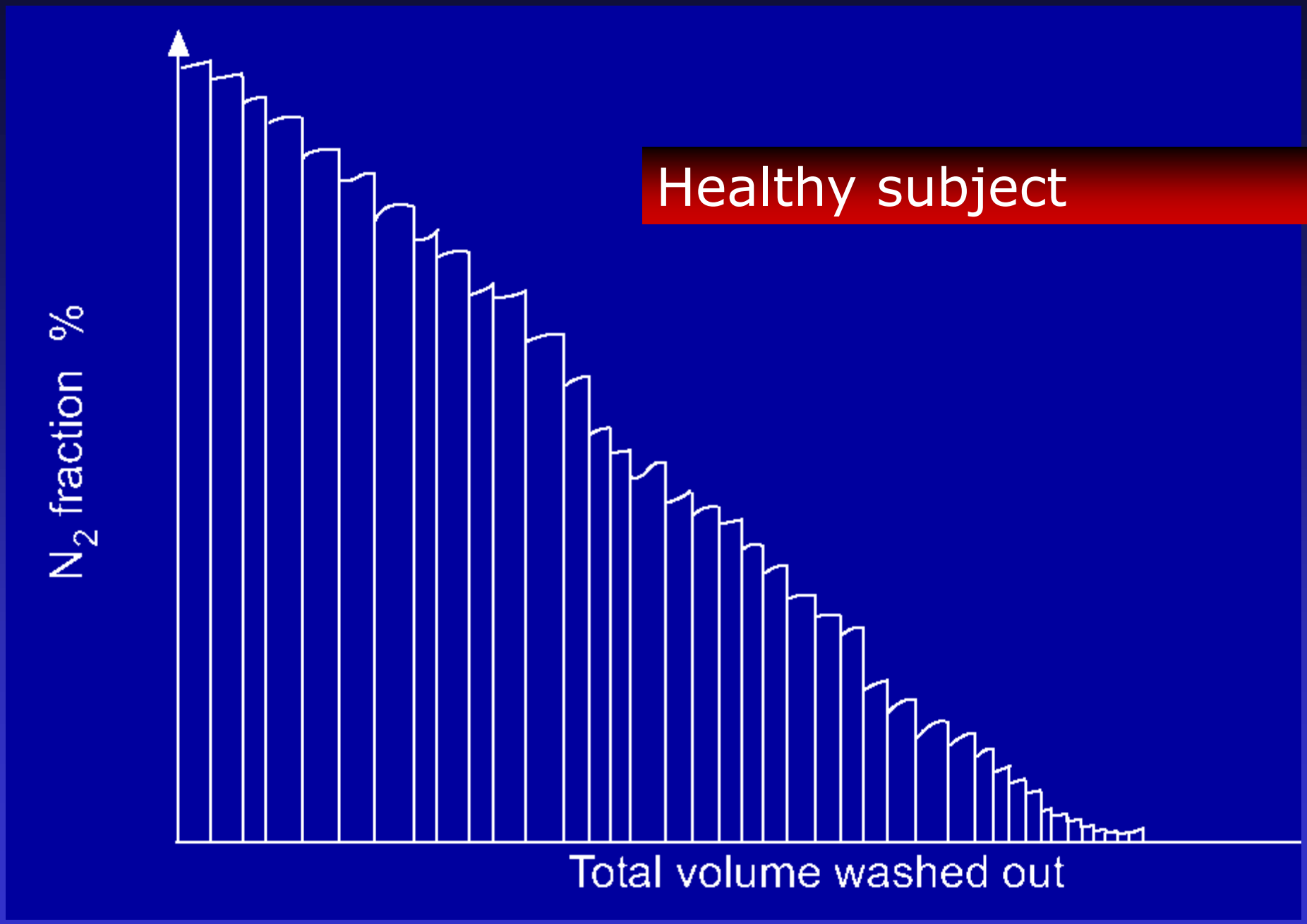
Wash-out of N_2

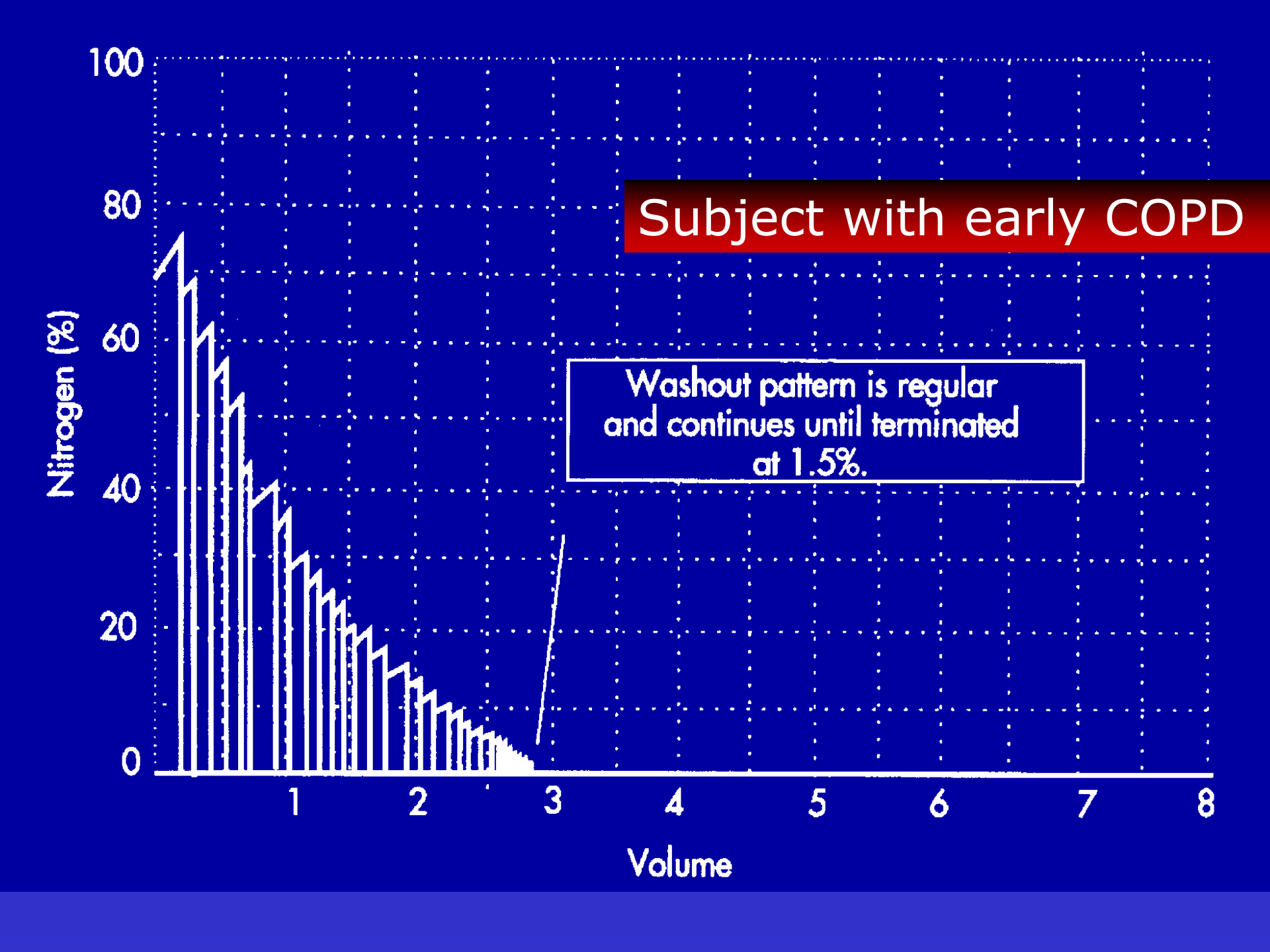
5 ml x 40% = 2 ml N_2

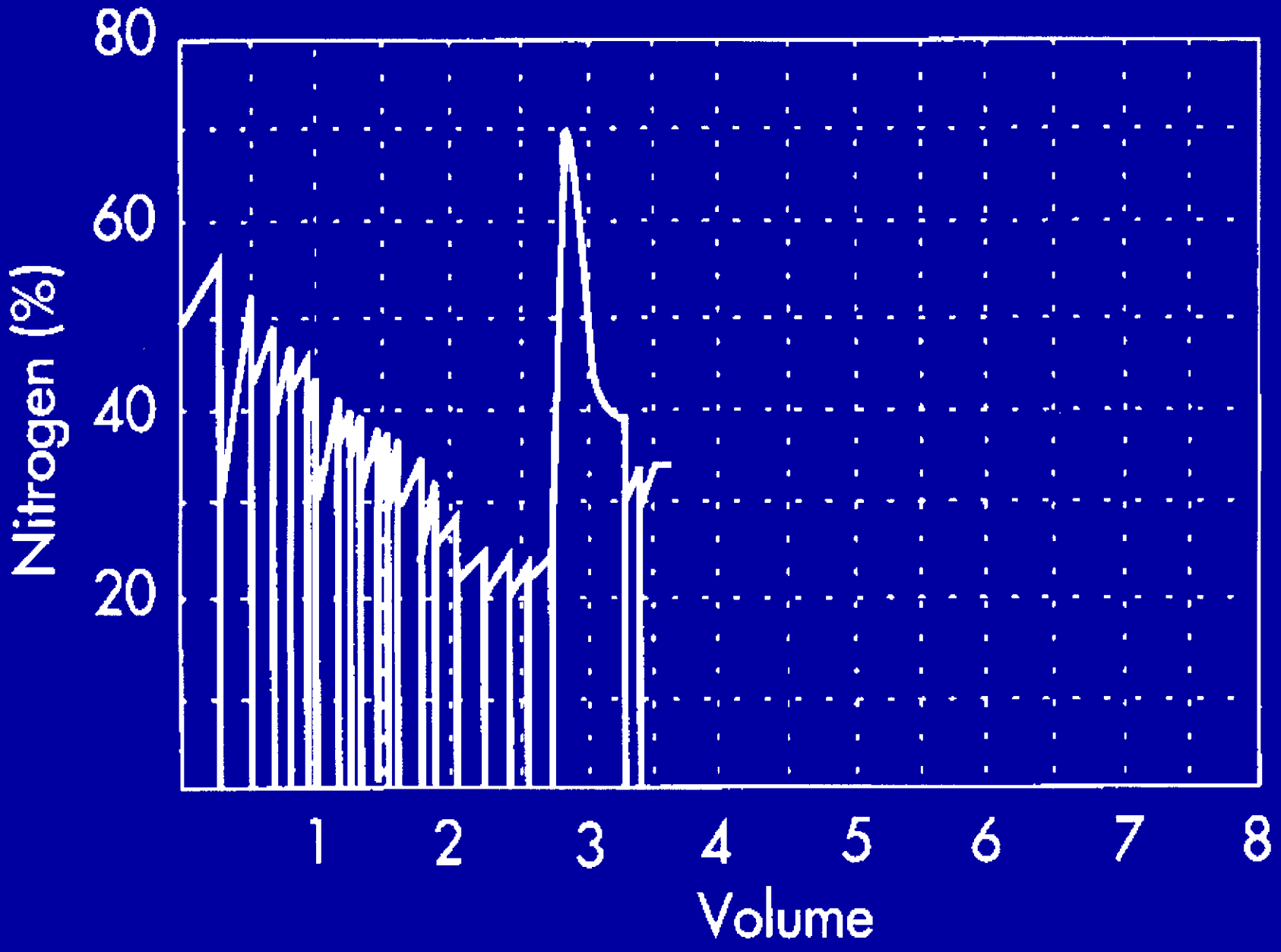

100
80
60
40
20
0
Nitrogen (%)
Area =
volume
N_2
1
2
3
4
5
6
7
8
Volume

Multiple-breath nitrogen wash-out techniques
Adaptation of Methodolgy

- Measurement of N_2 is replaced by measurement of exhaled O_2 and CO_2
- $N_2 = 100 - [O_2 + CO_2]$


Healthy subject
N_2 fraction %
Total volume washed out


Subject with early COPD
Washout pattern is regular and continues until terminated at 1.5%.
Nitrogen (%)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
Volume


80
60
40
20
Nitrogen (%)
1
2
3
4
5
6
7
8
Volume

Nitrogen Washout Technique Procedures

6. Monitoring of N_2 during washout
7. Measuring of exhaled volume
8. Stability of signal should be examined for noise and drift
   - $N_2 = 0$ during inspiration
   - configuration of end-expiratory N_2 curve
9. End of test: $[N_2] < 1.5\%$ for 3 breaths

Nitrogen Washout Technique Procedures

10. Repeat test if leak is reported or results are not physiological

11. Document
    - leaks
    - eardrum perforation
    - degree of effort during vital capacity maneuvers

12. 10 - 20 min between two tests

13. Take care of patients on O_2 therapy

N_2 Washout Technique

- Principle of technique
- Equipment
- Procedures
- Quality control

Multiple-breath N_2 washout techniques Pittfalls

- Phase difference between N_2 measurement (O_2 and CO_2 measurement) and volume measurement ---> biologic calibration