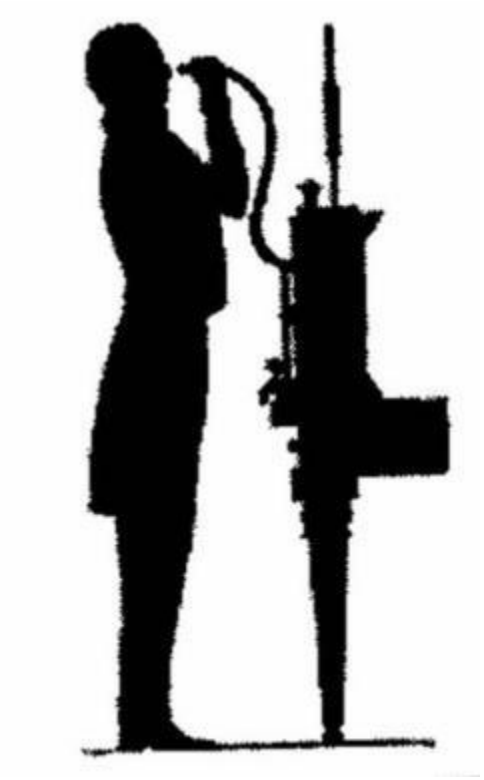
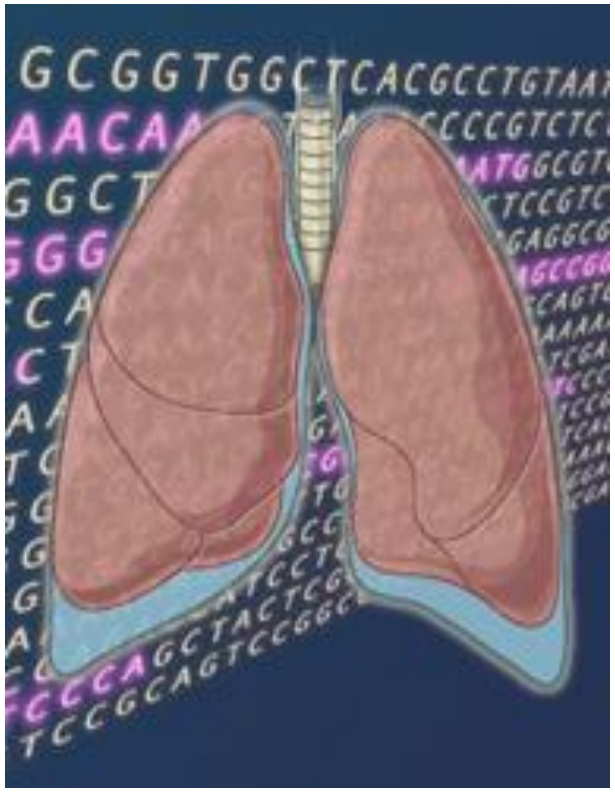
Pulmonary Function Testing
Past, Present, and Future





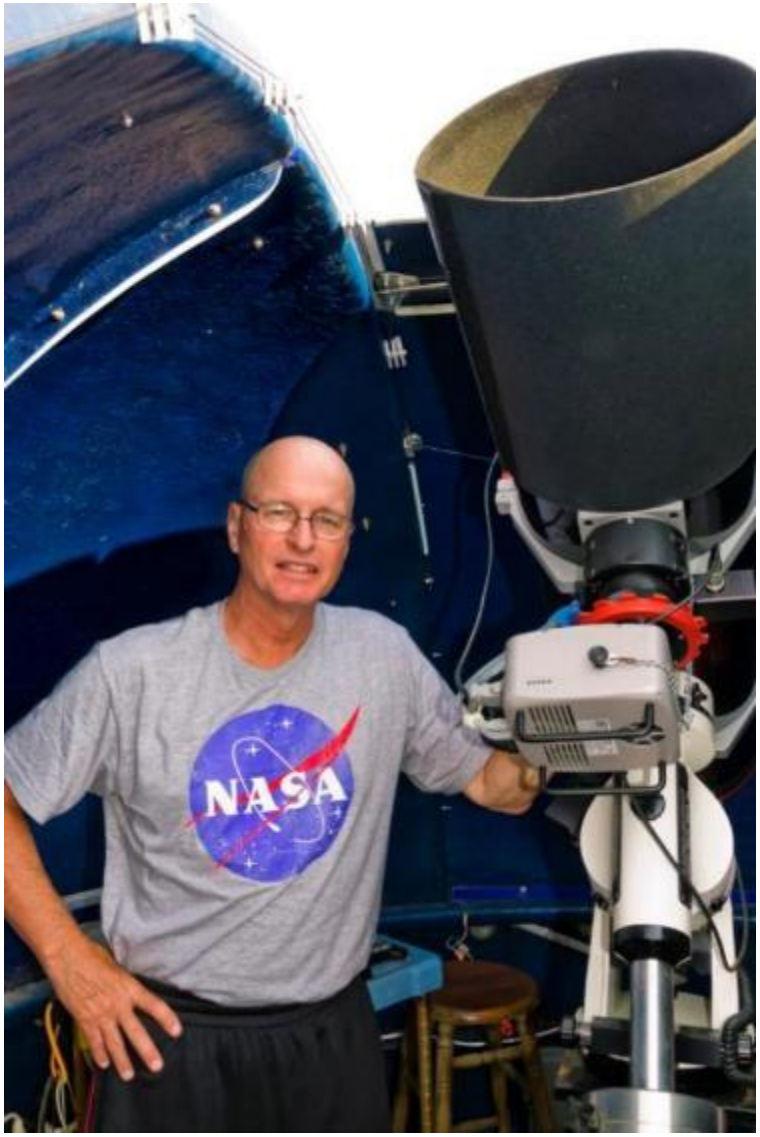


Gregg L. Ruppel, MEd, RRT, RPFT, FAARC
Adjunct Professor, Pulmonary, Critical Care & Sleep Medicine
Saint Louis University School of Medicine

What I used to do…



What I do now… RETIREMENT!!





PAST

(Where did we come from…?)

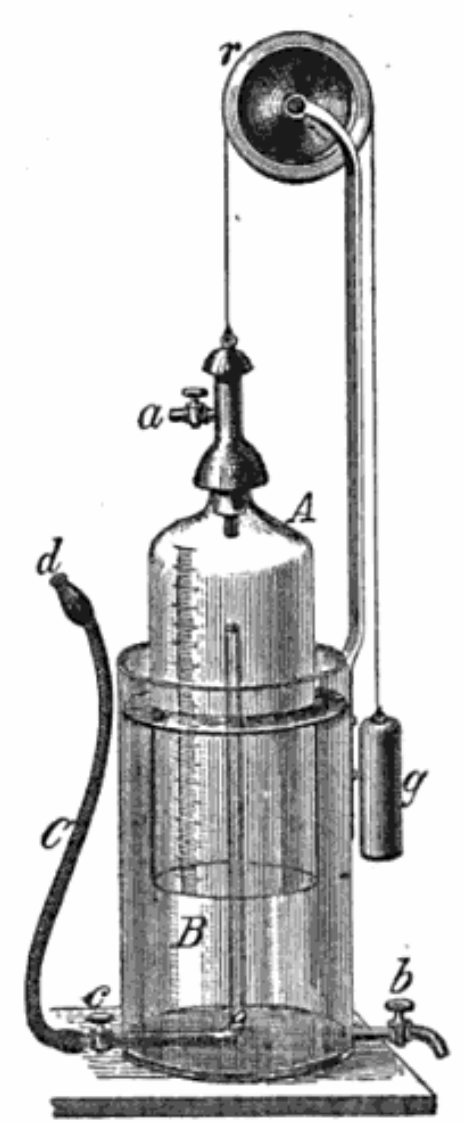


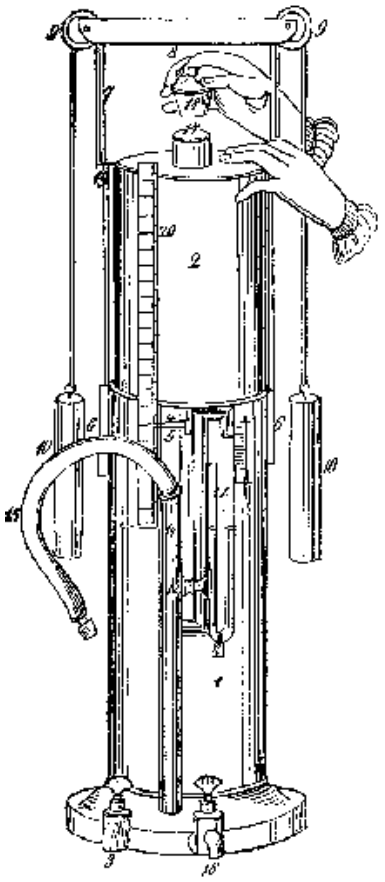
FIG. 248.—WINTRICH'S MODIFICATION OF HUTCHINSON'S SPIROMETER. (*Reichert.*)

Lung Volumes (Spirometry) - The Basis of Pulmonary Function Testing



"vital capacity"
"complemental air"
"breathing air"
"reserve air"
"residual air"

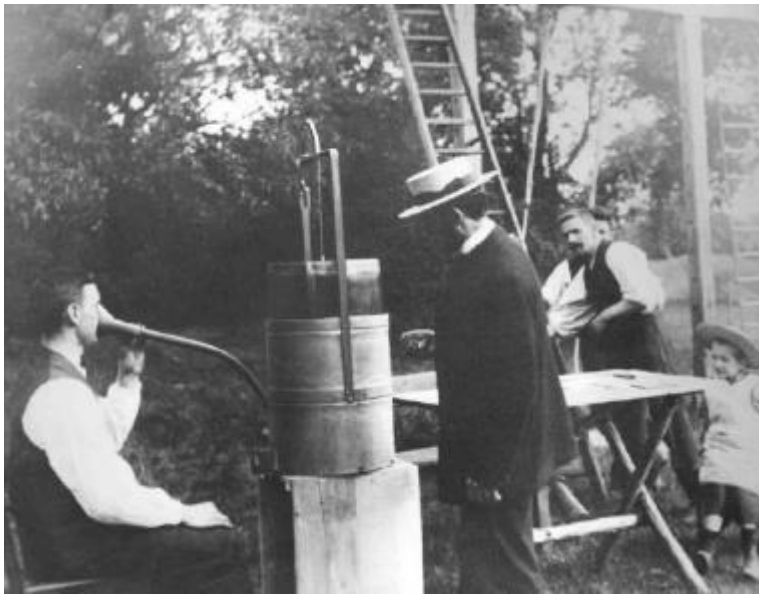
Predicted Values



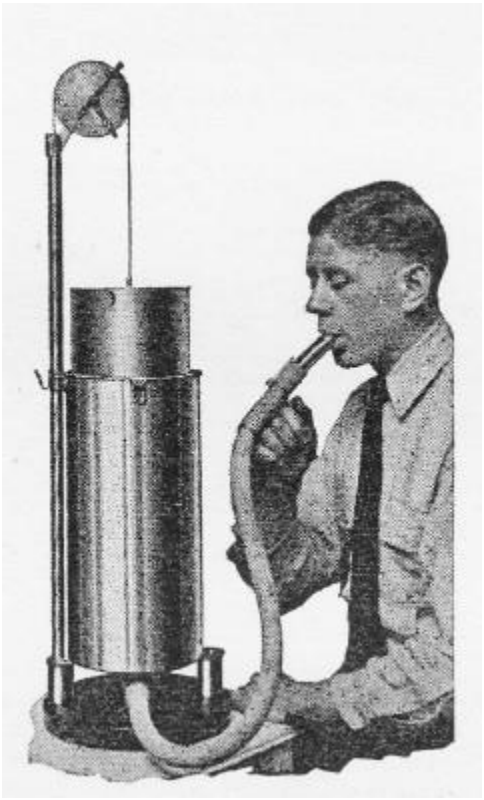
Spirometry



1890s

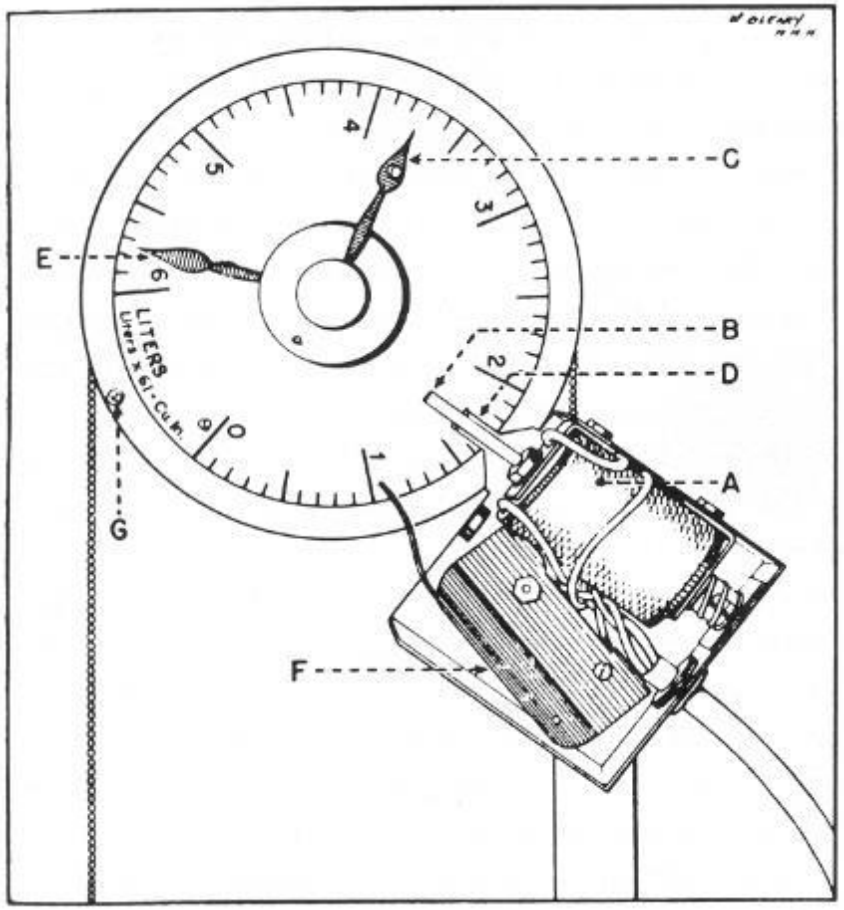


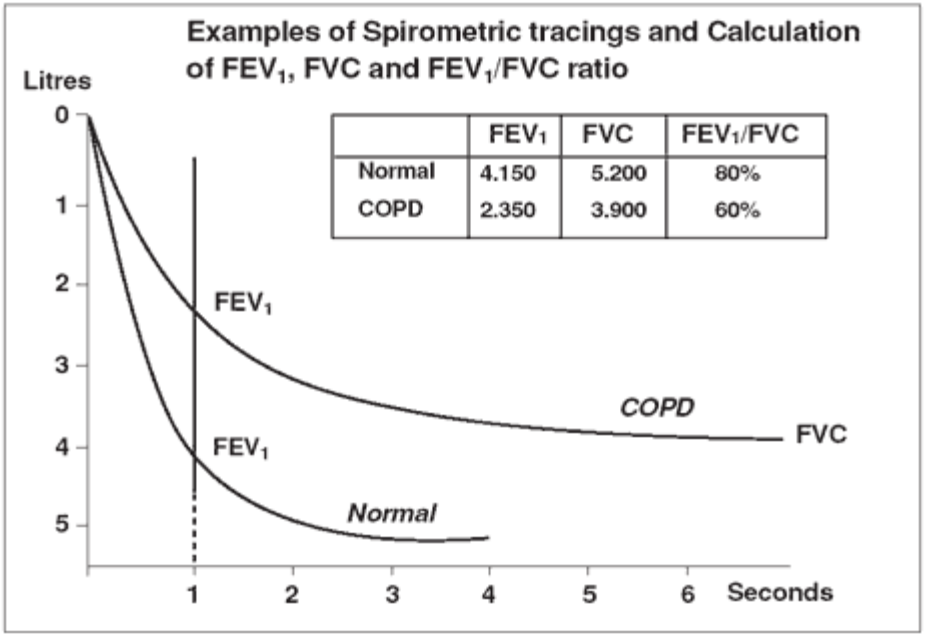
1900s



1930s

Gaensler's Microswitch





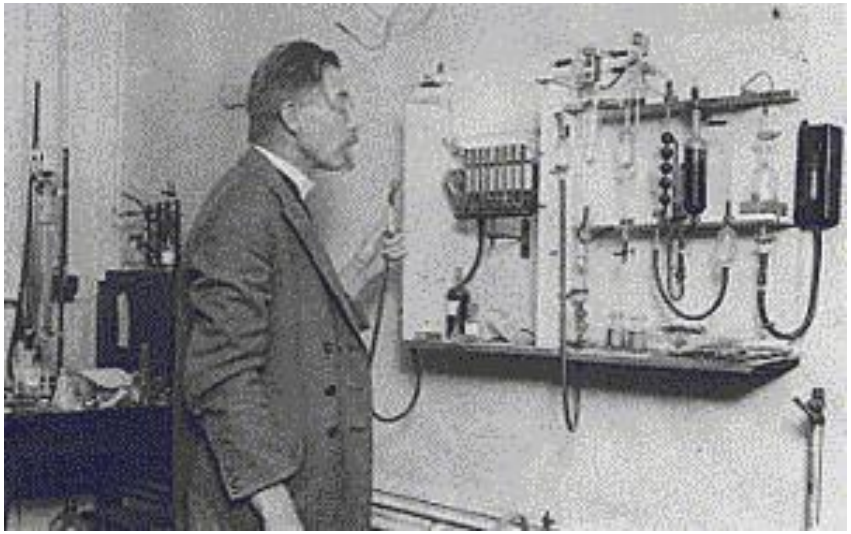
	FEV_1	FVC	FEV_1/FVC
Normal	4.150	5.200	80%
COPD	2.350	3.900	60%

Circa 1951

Great Moments in Spirometry

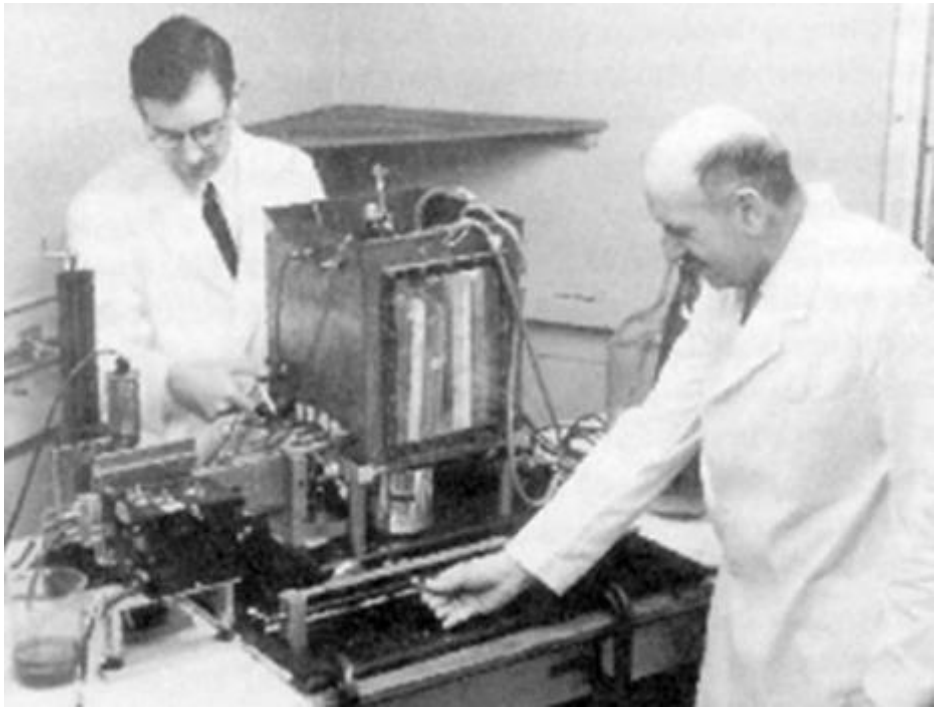
- 1938 Alvin Barach measures vital capacity following inhaled neosynephrine and adrenaline
- 1947 Robert Tiffeneau describes *capacité pulmonaire utilisable à l'effort (*FEV_1)
- 1951 EA Gaensler measures 'timed' vital capacity (FEV_1)
- 1955 Leuallen & Fowler propose MMEF ($FEF_{25-75\%}$)
- 1960s Robert Hyatt "finds" the flow-volume curve
- 1980s IBM introduces the 'personal computer'

DLCO Historical Perspective





Krogh and his micro-tonometer.
Stamp, Denmark, 1966



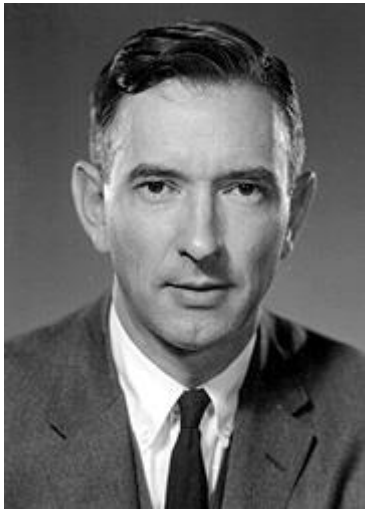
Forster and Roughton

DLCO Historical Perspective

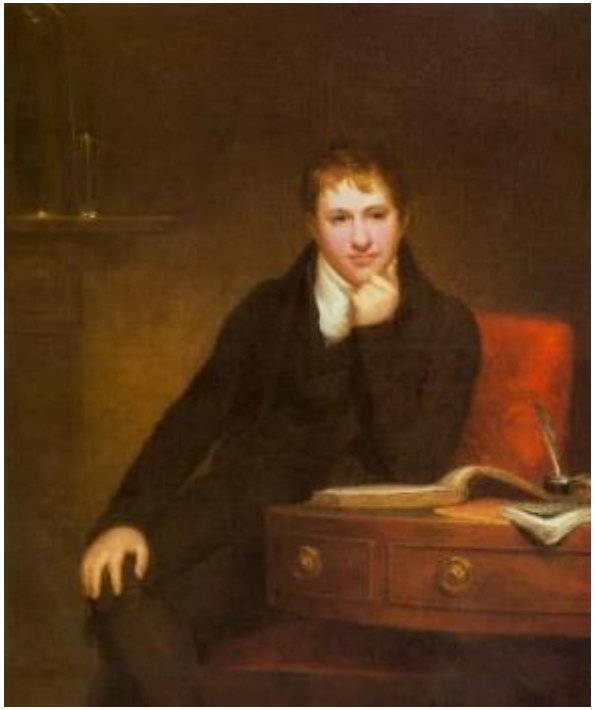
- August & Marie Krogh
  - disproved ‘oxygen secretion’
  - invented spirometer & microtonometer
  - measured CO uptake using a breat hold



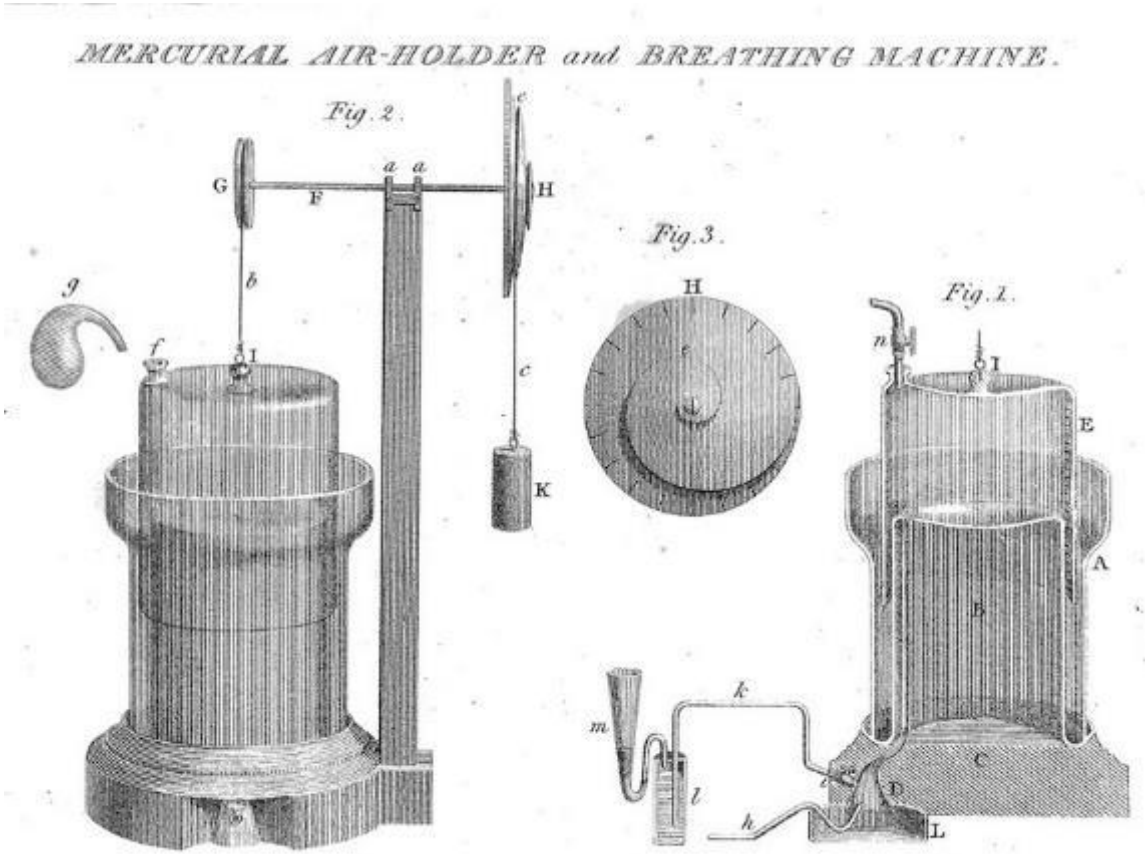
- Robert Forster II
  - used IR to measure CO
  - added He to estimate alveolar CO and V_A
  - described effect of O_2 on DLco



Lung Volumes

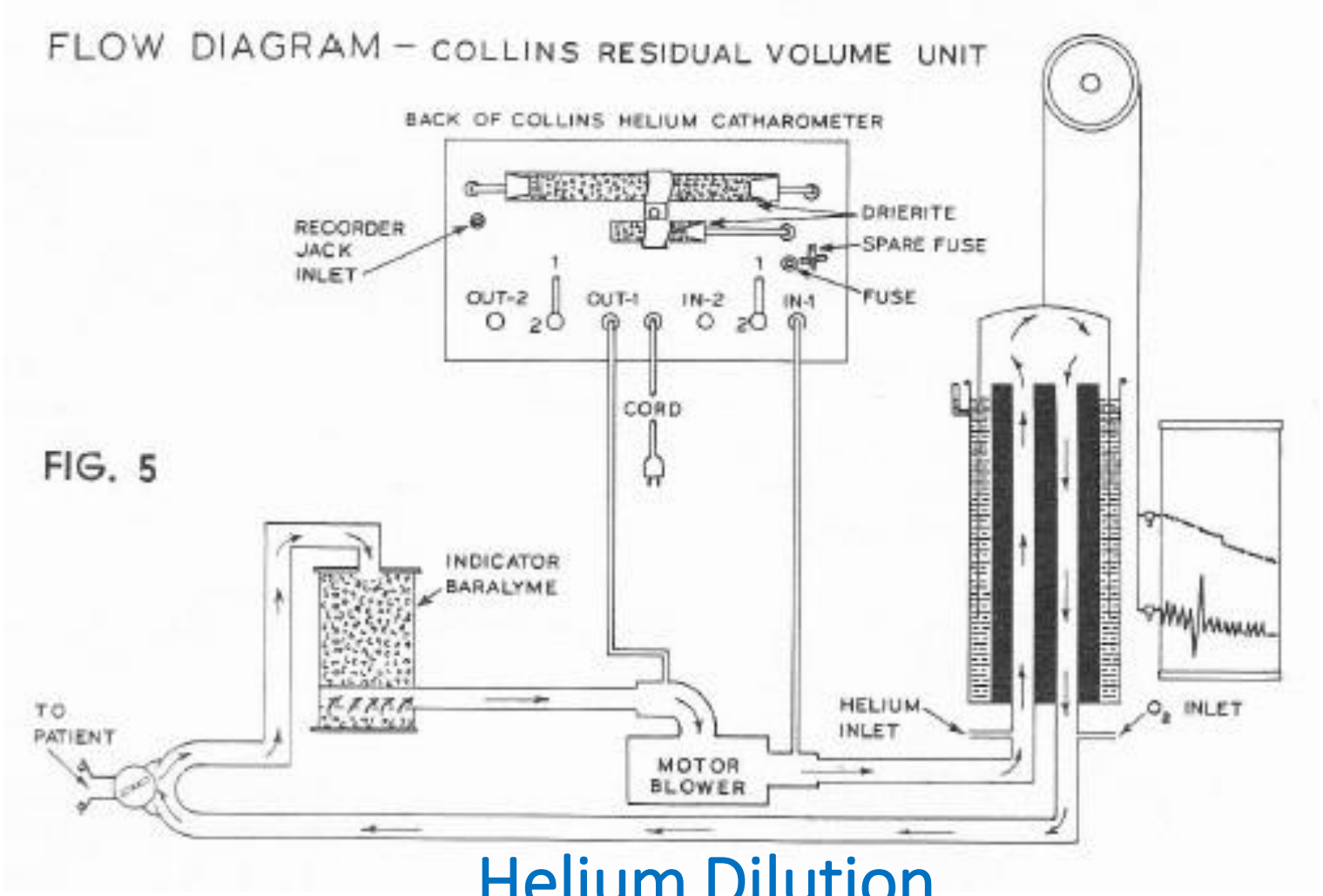


Sir Humphrey Davy



Circa 1800

Lung Volumes



Helium Dilution

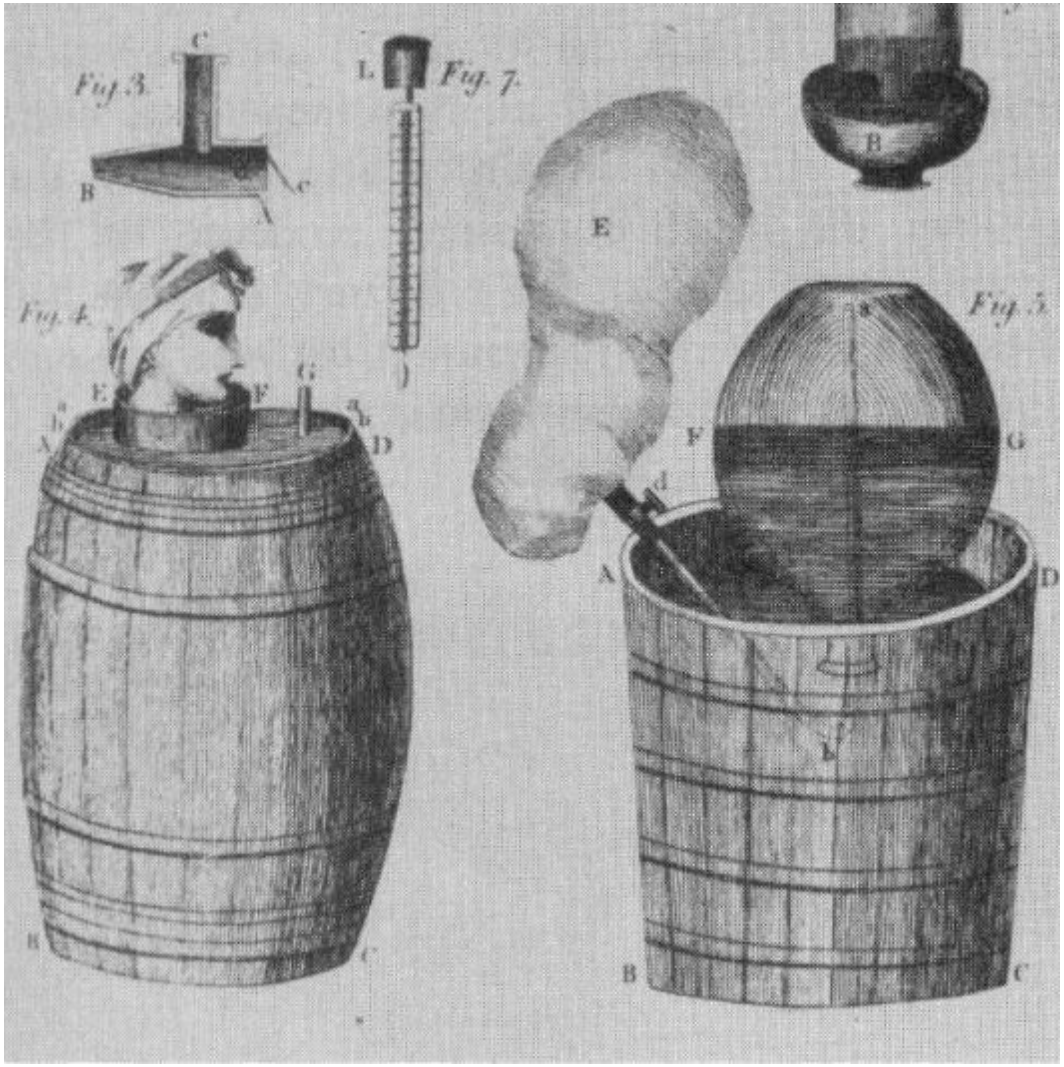
Lung Volumes



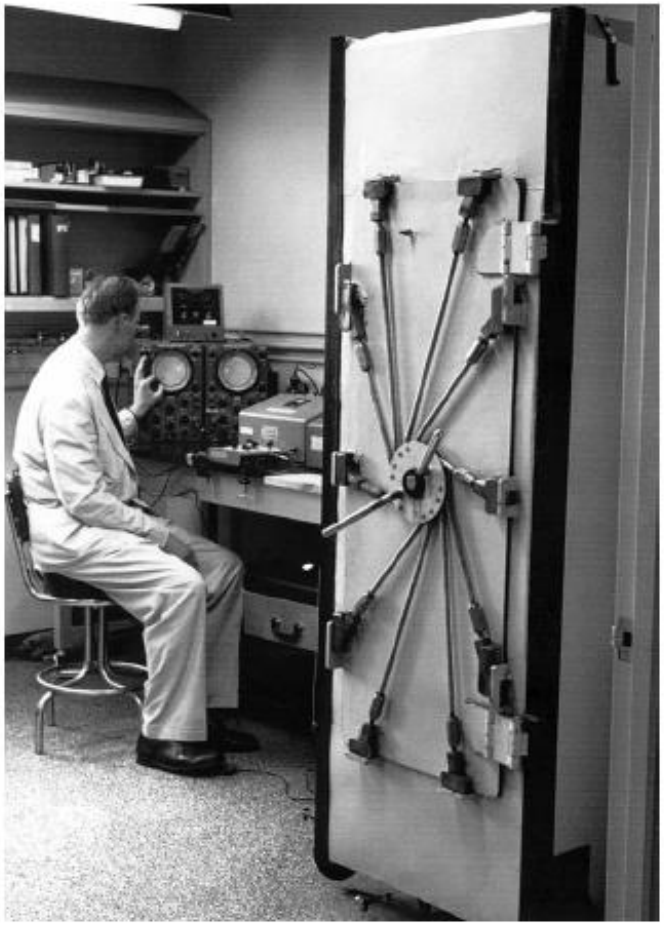
N2 Washout

Lung Volumes

Robert Menzies used a hogshead filled with water to measure tidal volume, circa 1796



Lung Volumes





Arthur Dubois and his body plethysmograph, circa 1959

Lung Volumes



circa 1960



circa 1980

Present

(Where are we now?)







Pulmonary Function Tests

Spirometry

FEV_1

FVC

FEV_1/FVC





DLCO

Diffusing Capacity

TLC

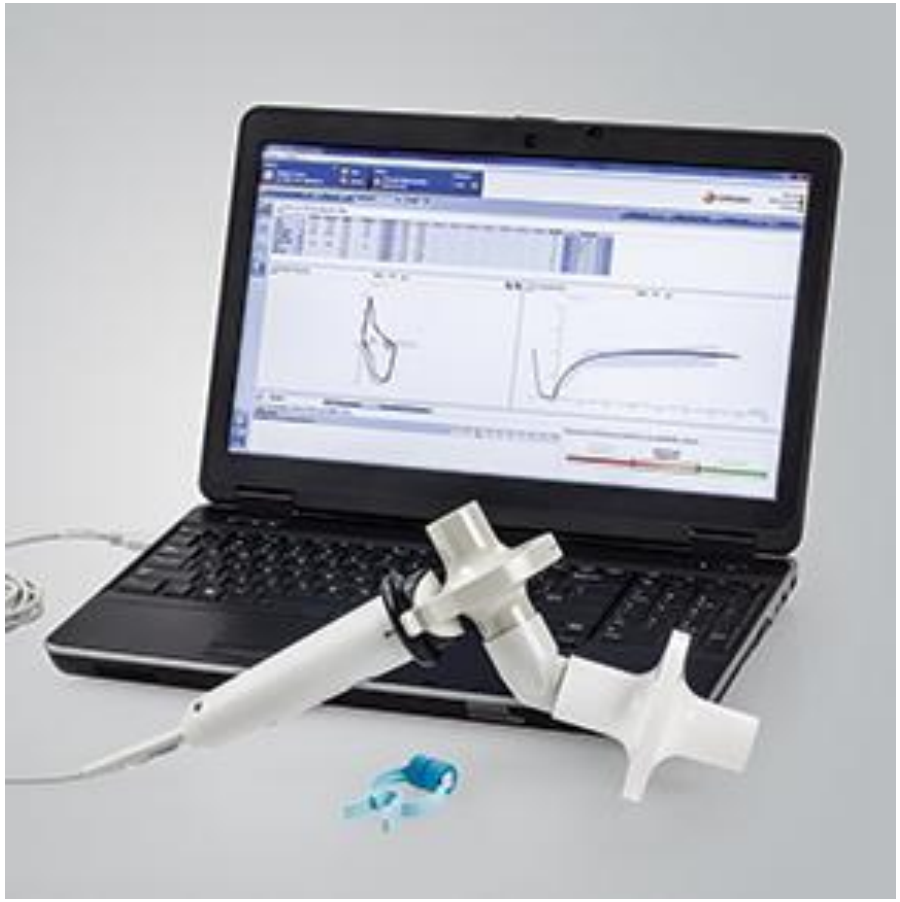
Lung volumes

Evidence basis for PFTs today

- Spirometry & DLCO
  - strong literature support
  - relatively clear indications
  - related to clinical outcomes
- Lung volumes
  - limited literature related to indications or outcomes

Spirometry by Microprocessor

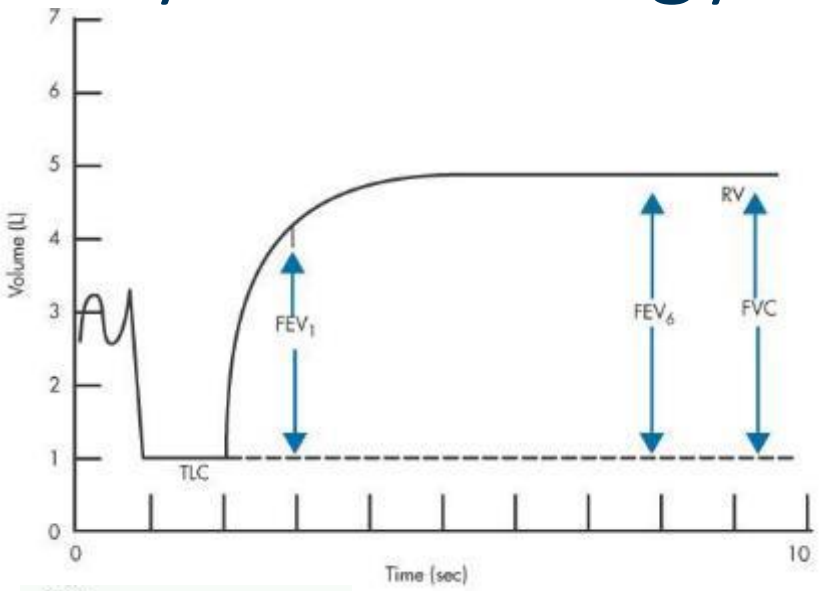
- Spirometry (FVC, VC, VC subdivisions)

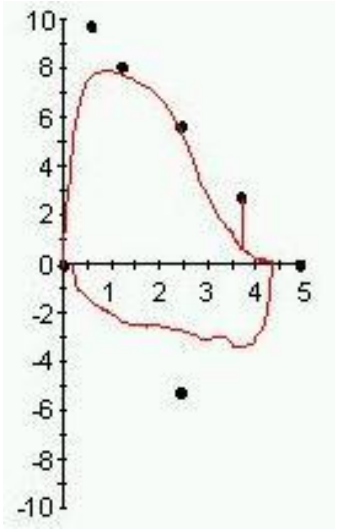




Spirometry Terminology

- FVC, FEV_1, FEV_1/FVC
- $FEV_{0.75}$
- FEV_3
- FEV_6
- ~~$FEF_{25-75\%}$~~
- PEF
- ~~$VMAX_X$~~





Spirometry Indications

- Diagnose presence/absence of lung disease
- Quantify decrease in lung function (pulmonary/cardiovascular/neuromuscular disease)
- Measure effect of occupational/environmental exposure
- Determine response to therapy
- Assess risk for surgical procedures
- Evaluate disability/impairment
- Epidemiology (*genetics?*)/research

DLCO Terminology

- DLCO (TLCO)
- DL/VA (TL/VA)
- KCO, Krogh's Coefficient
- VA (TLC–VD?)
- 1/Dm, 1/θVc
- DLNO



DLco Methodology

- Classical (CO, He) separate analyzers
- Gas chromatography (CO, Ne)
- Rapid, continuous (CO, CH_4) – "RGA"
- Molar mass (CO, He)

$$DL_{CO} \equiv \frac{V_A \, x \, 60}{(P_B - 47) \, x \, (T)} \, x \, Ln\left[\frac{F_A Tr}{F_A CO_T}\right]$$

$$V_A \equiv \left(V_I - V_D\right) x \frac{F_I T_r}{F_A T_r} \, x \, STPD \;\; factor$$

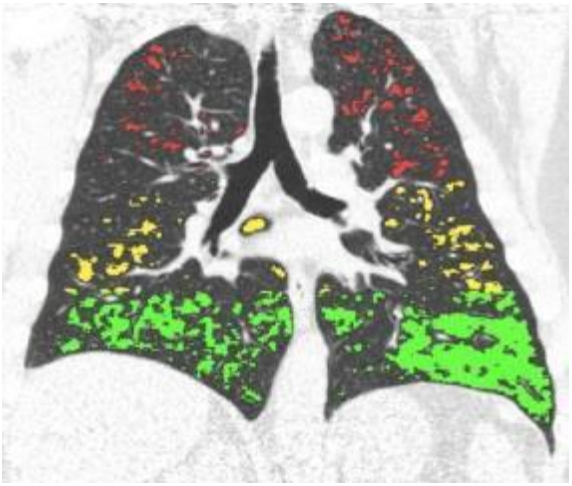


DLCO Indications

- Obstructive lung disease (emphysema vs. others)
- Restrictive lung disease (ILD, sarcoidosis, chemo/radiation, drugs)
- Pulmonary vascular disease (emboli, PAH, SLE, RA, etc.)
- Pre-op evaluation lung resection
- Disability evaluation
- Risk for O_2 desaturation

Lung Volumes

- Multibreath gas dilution/washout techniques
- Single breath gas dilution /washout
- Body plethysmography
- Radiologic estimation
- HRCT







Lung 'Volume' Terminology

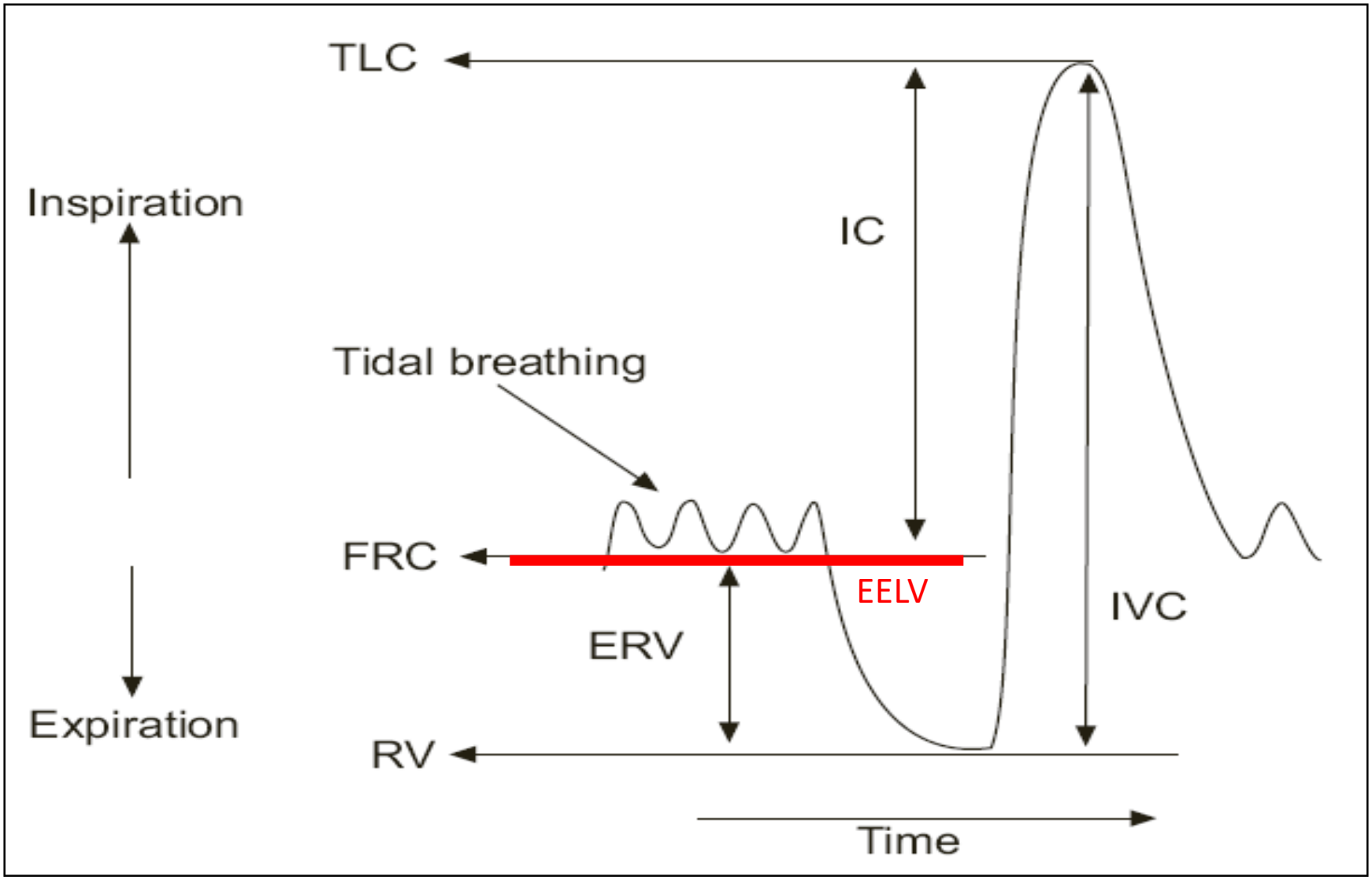
Capacities

- **VC** (Vital Capacity):
  IRV+TV+ERV
- **TLC** (Total Lung Capacity):
  TV+IRV+ERV+RV
- **FRC** (Functional Residual Capacity):
  RV+ERV
- **IC** (Inspiratory Capacity):
  TV+IRV

Volumes

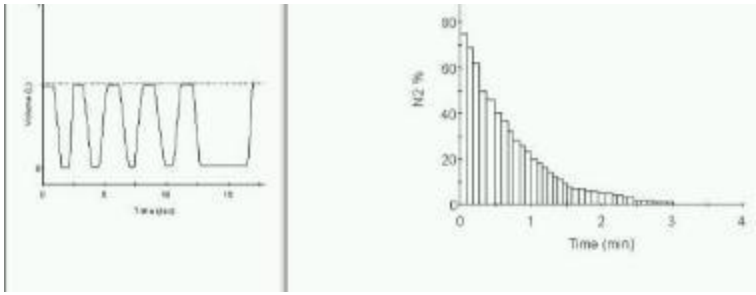
- **TV** (Tidal volume)
- **IRV** (Inspiratory Reserve Volume)
- **ERV** (Expiratory Reserve Volume)
- **RV** (Residual Volume)

Lung Volumes



Lung Volumes Indications

- Differentiate between obstructive and restrictive disease patterns (↓ FVC)
- Assess the response to therapy (bronchodilator, chemotherapy, radiation)
- Aid in the interpretation of other lung function tests (D_L/V_A, SGaw)
- Preoperative assessment when procedure will affect lung function (LVRS, pneumonectomy)
- May be useful for predicting mortality (IC/TLC)
- Characterize resting/dynamic hyperinflation (IC)



PFT Standards

- 1978 Epidemiology Standardization Project
- 1979 American Thoracic Society (spirometry)
- 1984 ATS (spirometry, DLco)
- 1991 ATS (interpretive strategies, predicted values)
- 1993 ERS (spirometry, lung volumes)
- 1994 ATS (spirometry, DLco update)
- 2005 ATS/ERS (spirometry, lung volumes, DLco, interpretive strategies, general considerations)
- 2014 ATS/ERS Field Walking Tests in Chronic Respiratory Disease
- 2017 ATS/ERS (DLco - RGA)
- 2017 ATS Standardized pulmonary function reporting
- 2017 ERS Bronchial challenge

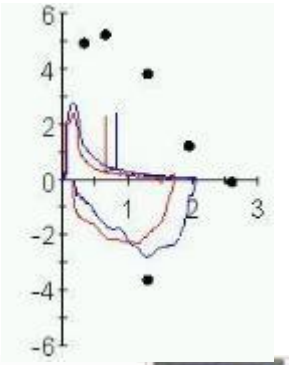
Other Standardization Efforts

- AARC Clinical Practice Guidelines (1992 -)
- British Thoracic Society (1994)
- ATS Pulmonary Function Lab Manual (1998, 2005, 2016)
- ATS Bronchial Challenge Testing (1999)
- ATS Six Minute Walk Test (2002)
- ATS/ACCP Cardiopulmonary Exercise Testing (2003)
- ATS Exercise-induced Bronchoconstriction (2012)

Effects of Standardization

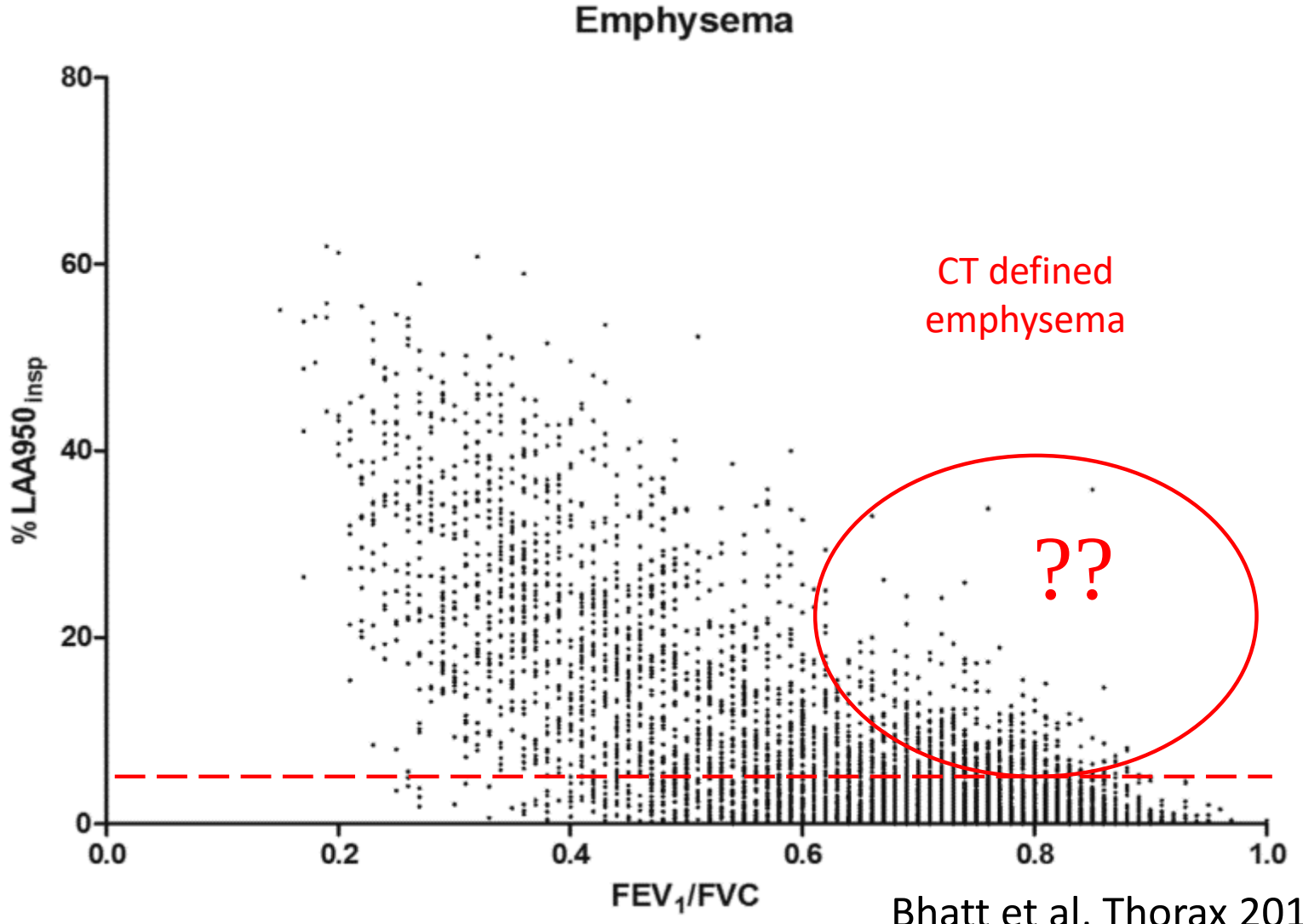
- **Equipment standards**
  - Spirometers (volume, flow-based)
  - Gas analyzers (DLco, lung volumes)
  - Plethysmographs
- **Testing procedures**
  - Acceptability criteria for each test category
  - Repeatability criteria
- **Quality Control**
  - 3 L Syringe
  - Simulators, Biologic controls (normal subjects)
- **Interpretation guidelines and strategies**
  - Data quality
  - Selection of appropriate predicted values
  - Diagnostic criteria (obstruction, restriction, mixed patterns)





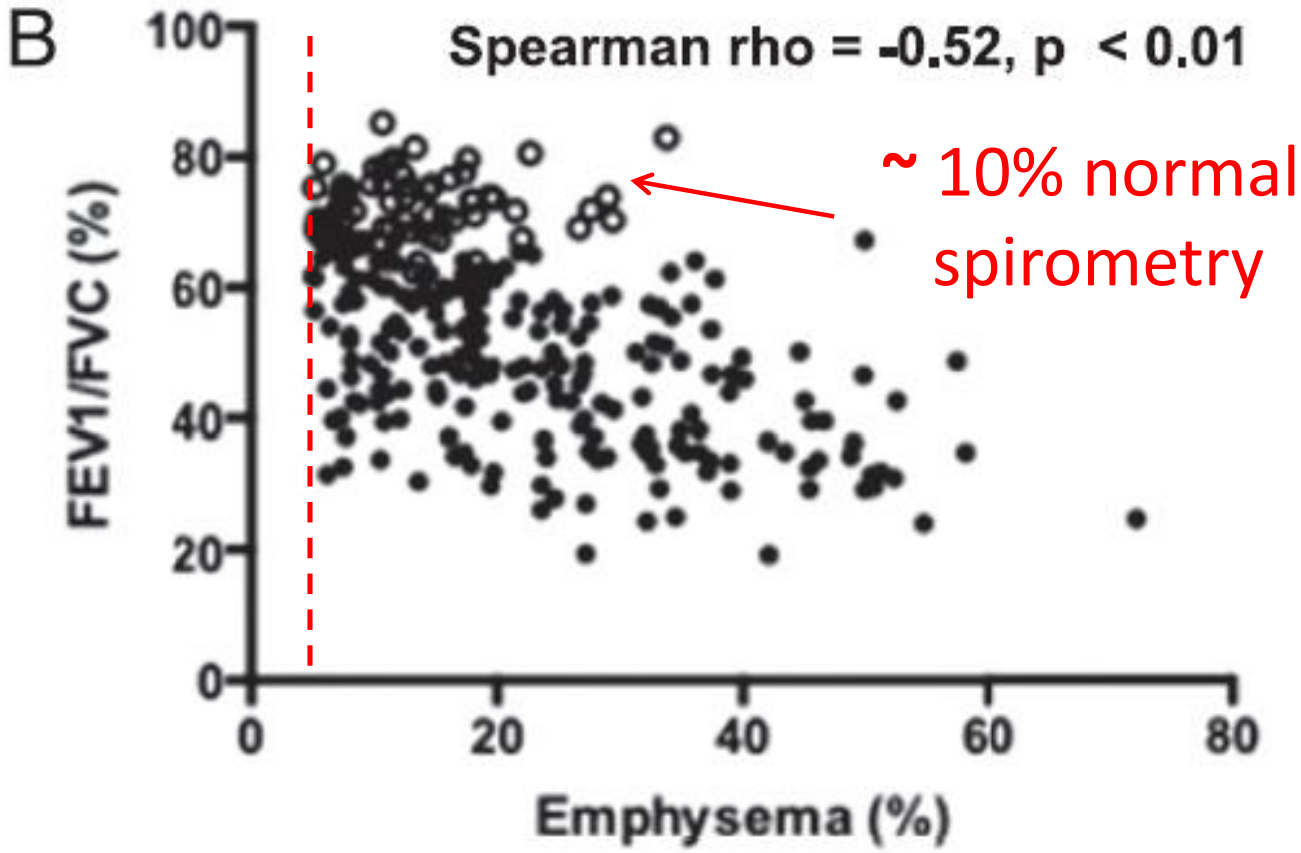


Physiology (PFTs) vs Imaging



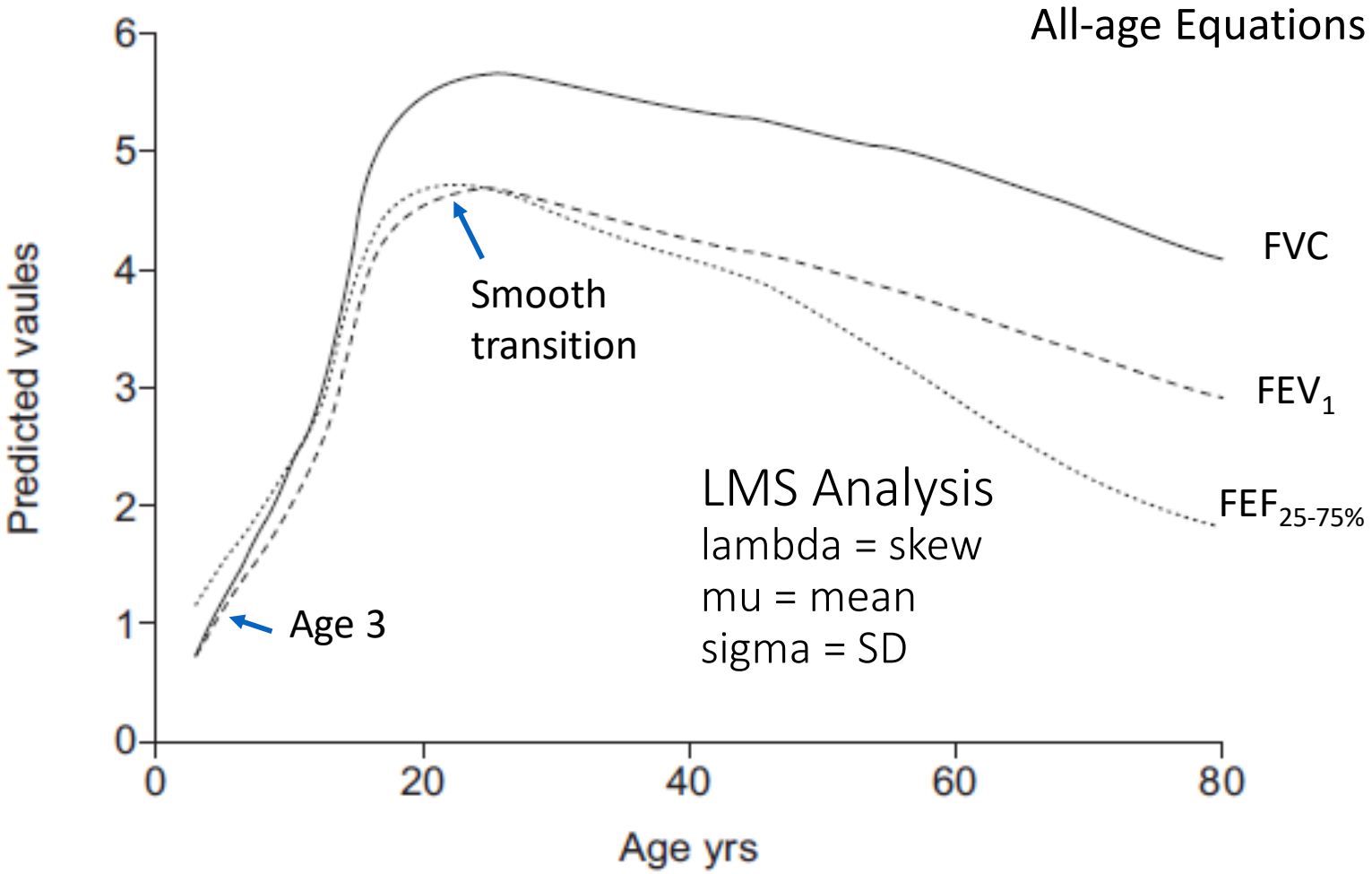
Bhatt et al, Thorax 2014

Physiology (PFTs) vs Imaging



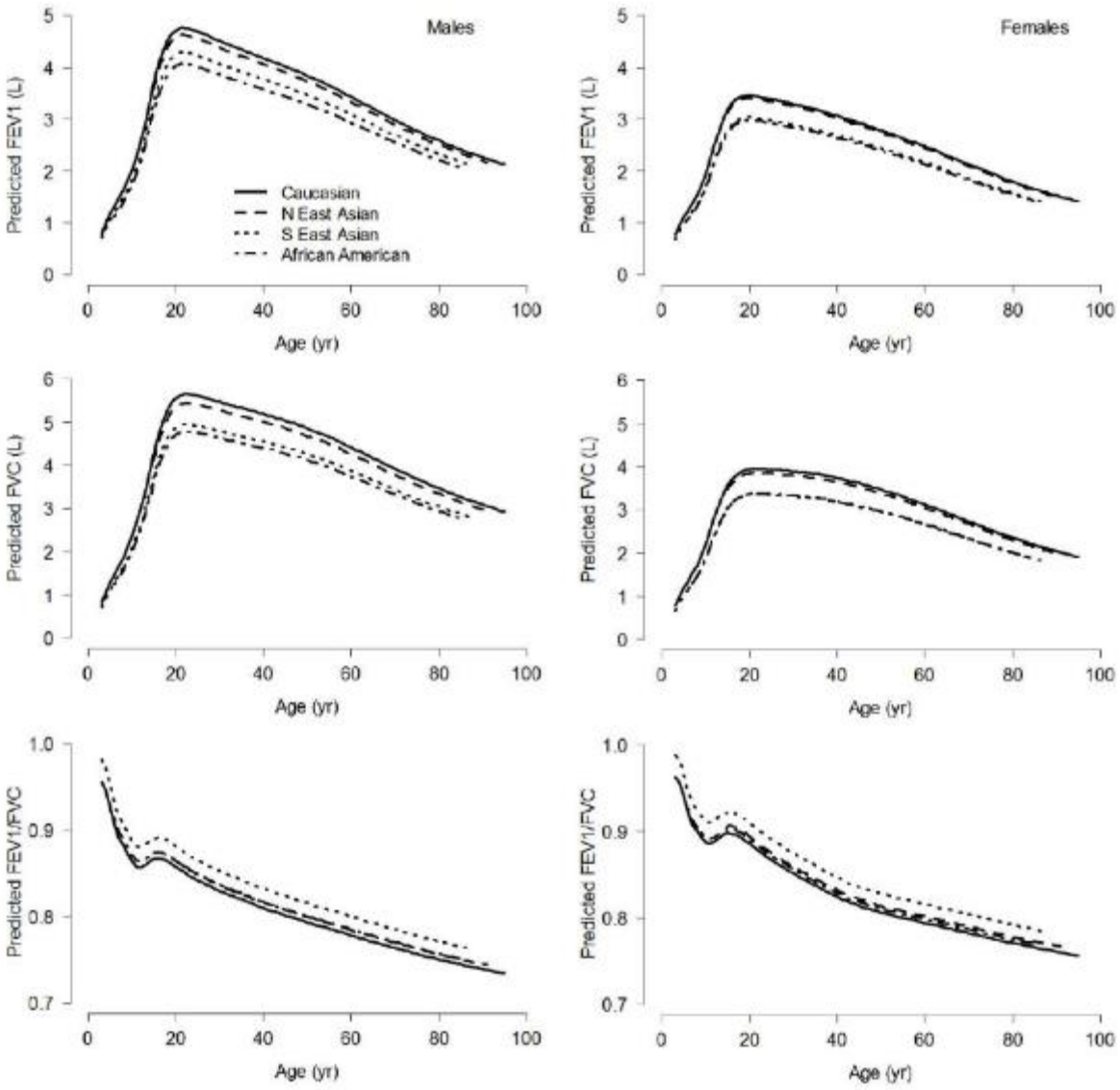
Lutchmedial et al: CHEST 2015; 148(1): 176 - 184

Predicted Values



Stanojevic & Stocks, ERJ 2010

Predicted Values



GLI-2012

Global Lungs Initiative

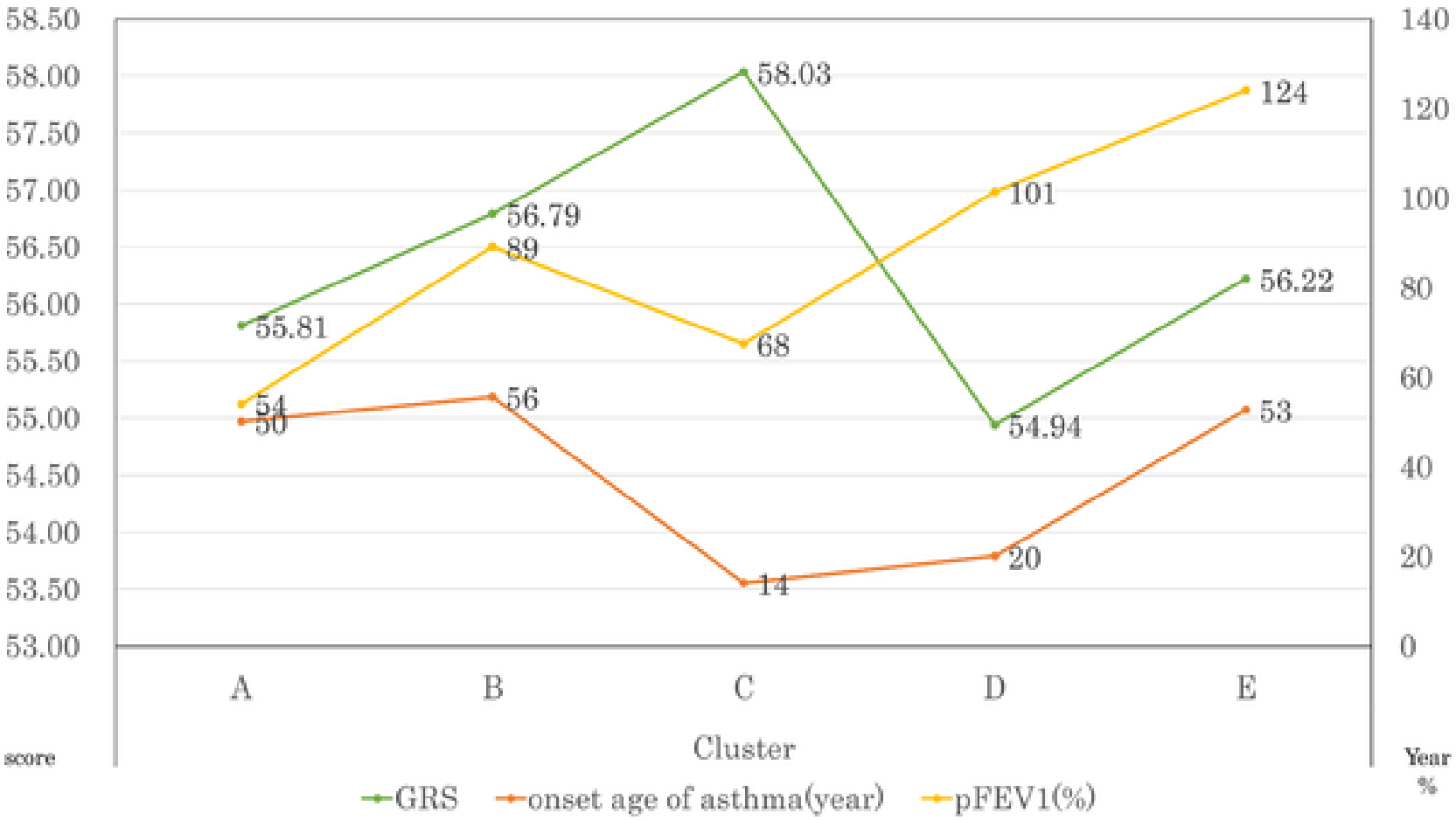
N = 72,031
Ages 3-95

Future

(Some things to watch for…)



Genes and Lung Function

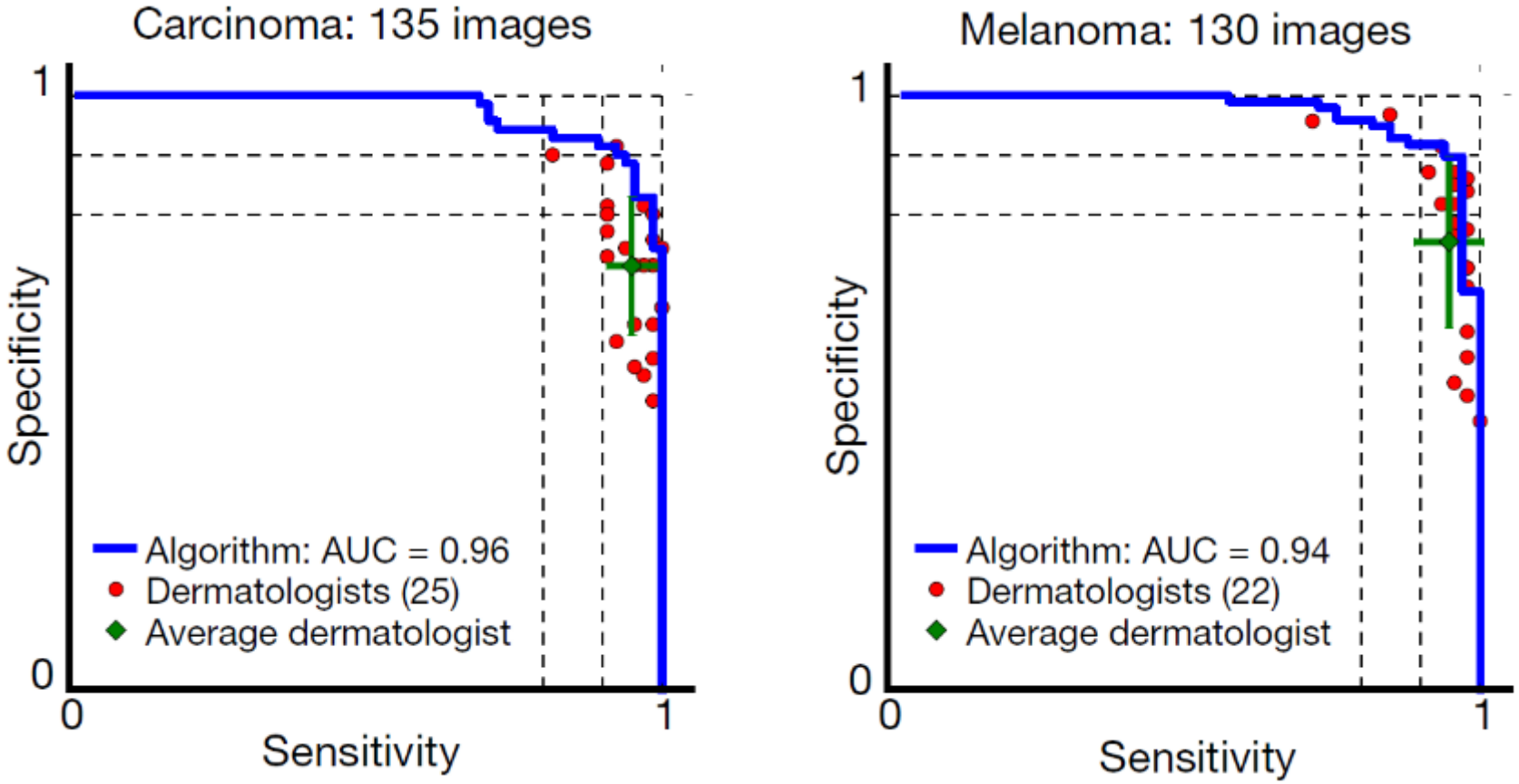


Differences in GRS, age at onset, and pFEV1 among asthma clusters.

Yamada , et al. (2016) Role of Lung Function Genes in the Development of Asthma. PLOS ONE 11(1): e0145832.

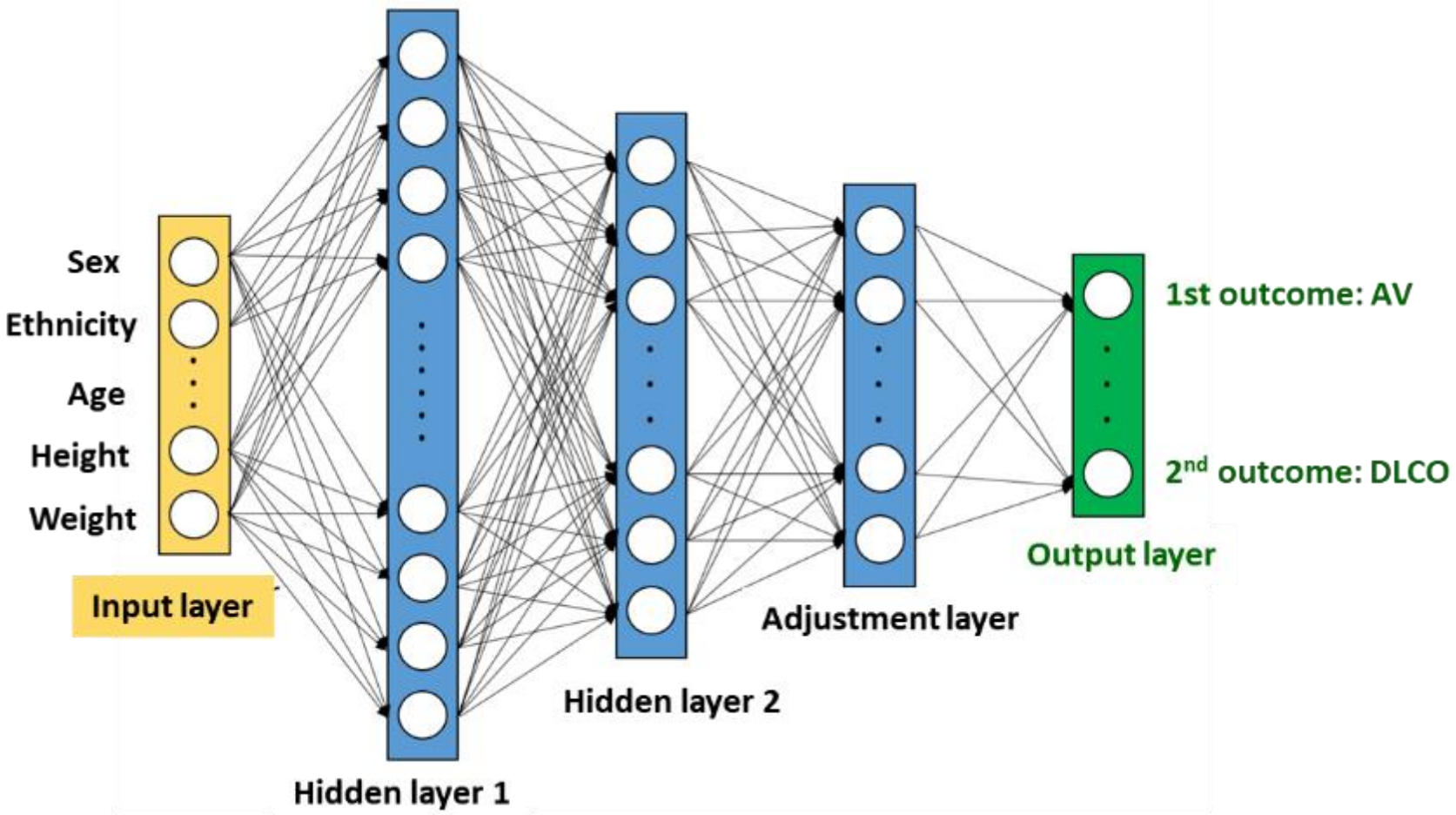
Artificial Intelligence (AI)

Convolutional Neural Networks



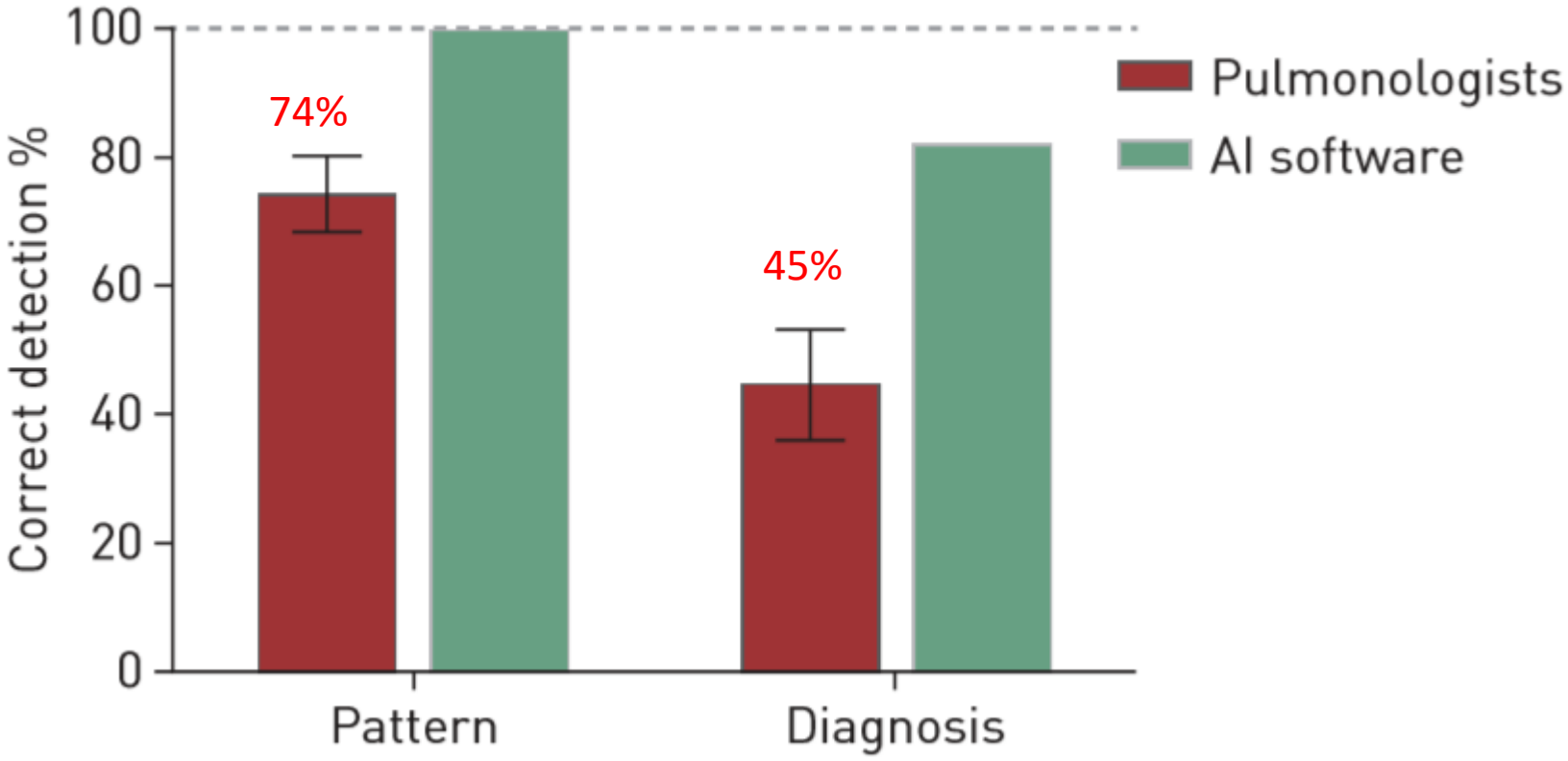
Esteva et al: Nature 2017, 542:115-118

Artificial Intelligence (AI) Deep Learning



Courtesy Nam Le Dong

Pulmonologists vs. AI



120 Pulmonologists x 50 test cases = 6000 Dx

Topalovic et al,
Eur Respir J 2019

Questions ??



Messier 3 – Globular Cluster