Using Cardiopulmonary Exercise Testing to Understand Exertional Dyspnea

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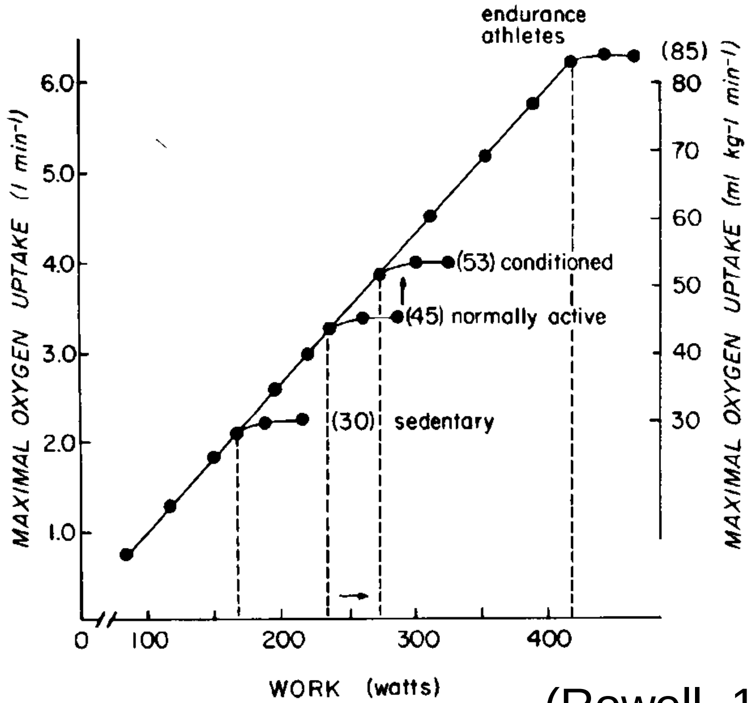
Lung Health

Exercise as a stress on gas exchange



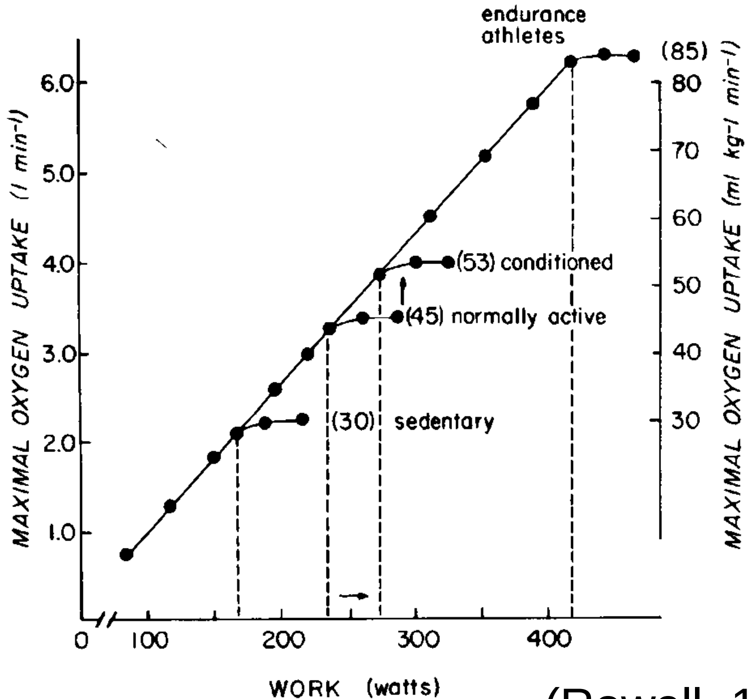
(Rowell, 1993)

$$VO_2 = (HR \times SV) \times (CaO_2 - CvO_2)$$

$$DLO_2 = \frac{\dot{V}O_2}{AaDO_2}$$

$(PAO_2 - PaO_2)$

Exercise as a stress on gas exchange



(Rowell, 1993)

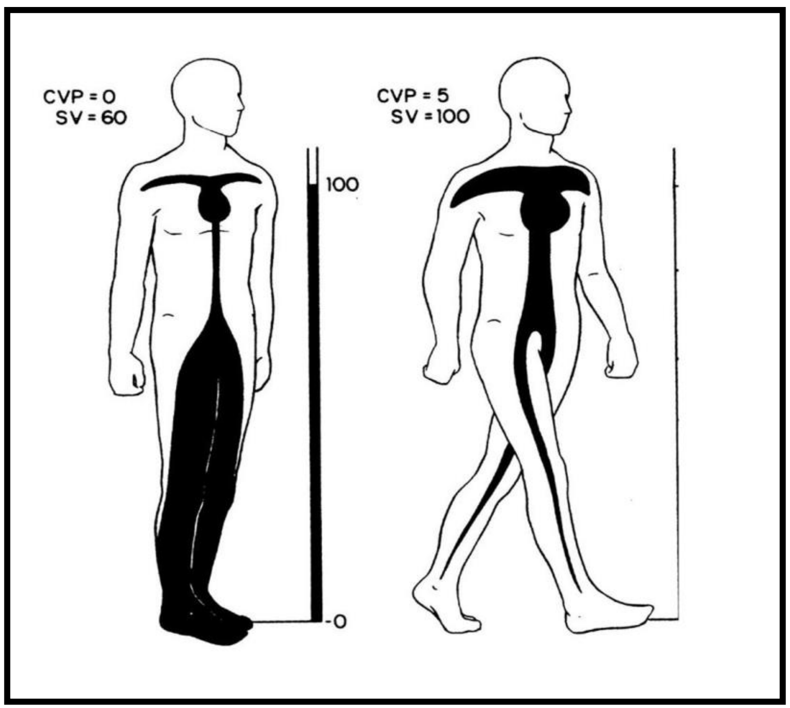
$VO_2 = (HR \times SV) \times (CaO_2 - CvO_2)$

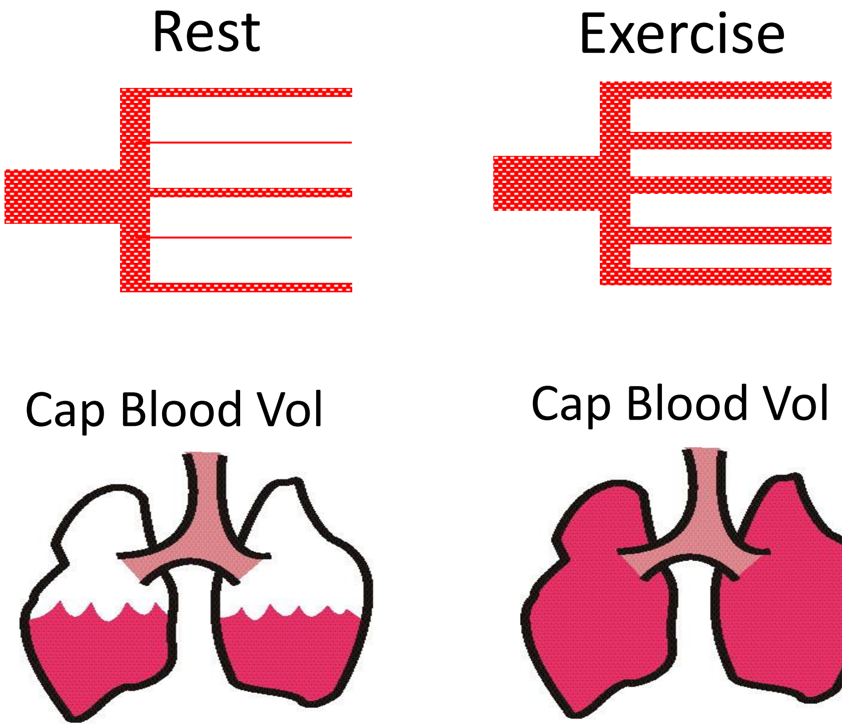
$$DLO_2 = \frac{\uparrow \dot{V}O_2}{\uparrow AaDO_2}$$

$(PAO_2 - PaO_2)$

$\uparrow AaDO_2 \rightarrow \downarrow PaO_2$

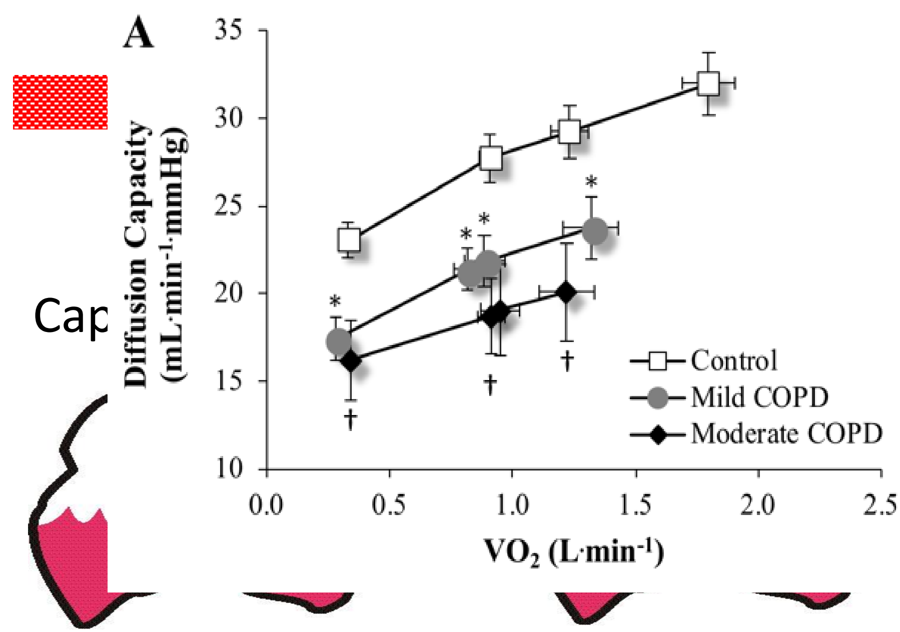
$$\underset{(PAO_2 - PaO_2)}{AaDO_2} = \frac{\uparrow \dot{V}O_2}{\uparrow DLO_2}$$





$$\underset{(PAO_2 - PaO_2)}{AaDO_2} = \frac{\uparrow \dot{V}O_2}{\uparrow DLO_2}$$

Rest Exercise



(Tedjasaputra et al. *Under Review*)

Exercise as a stress on ventilation

$$PACO_2 \sim \frac{\dot{V}CO_2}{\text{Alveolar Ventilation}}$$

$$PAO_2 \sim \frac{\text{Alveolar Ventilation}}{\dot{V}O_2}$$

$PACO_2$ = Alveolar PCO_2

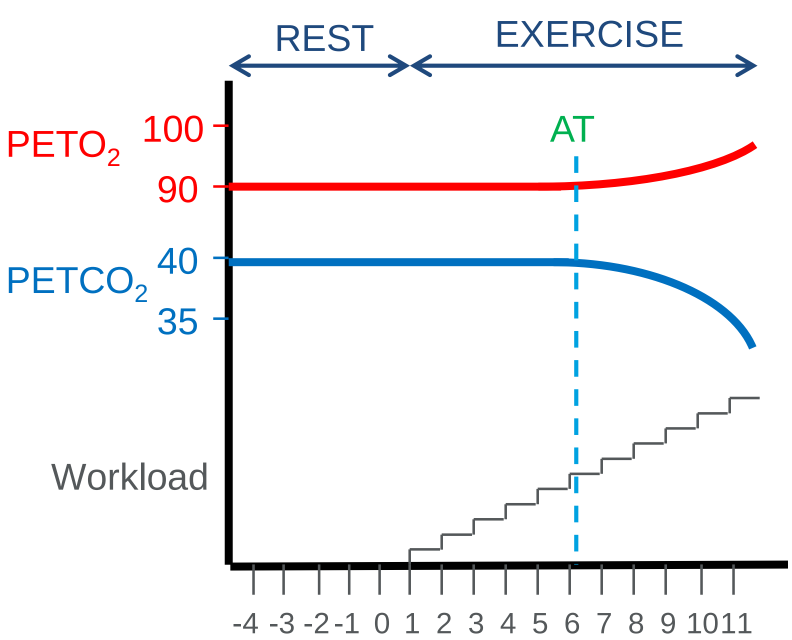
PAO_2 = Alveolar PO_2

$$PETCO_2 \sim \frac{\dot{V}CO_2}{\text{Alveolar Ventilation}}$$

$$PETO_2 \sim \frac{\text{Alveolar Ventilation}}{\dot{V}O_2}$$

$PETCO_2$ = Alveolar PCO_2

$PETO_2$ = Alveolar PO_2



	Untrained	Trained
$\dot{V}O_{2max}$ L/min	3.0	5.0
$PETCO_2$ mmHg	30	30
$\dot{V}_E$ L/min	109	182

$$P_{ET}CO_2 \sim \frac{\dot{V}CO_2}{\text{Alveolar Ventilation}}$$

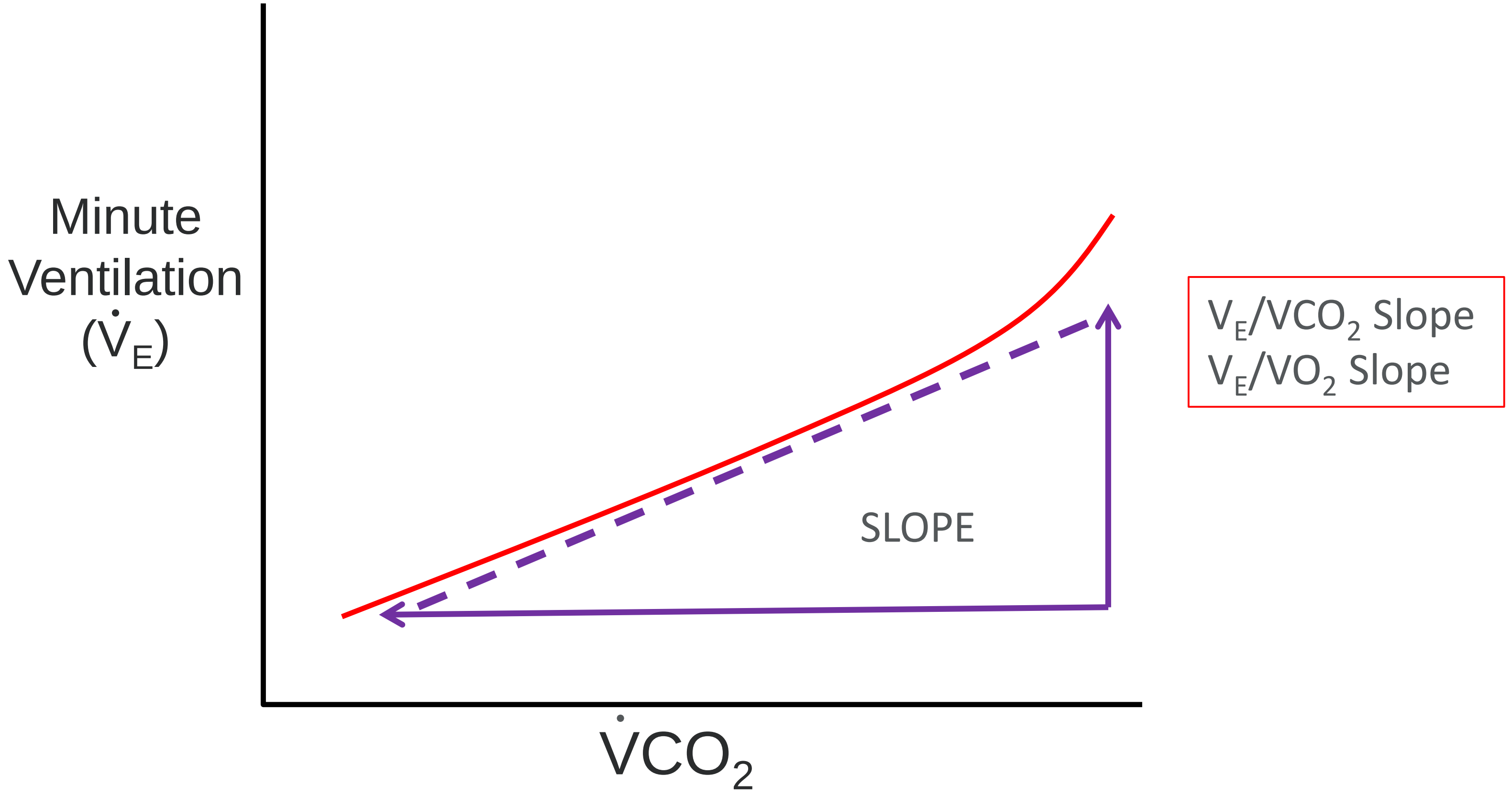
$$P_{ET}O_2 \sim \frac{\text{Alveolar Ventilation}}{\dot{V}O_2}$$

$P_{ET}CO_2$ = Alveolar PCO_2

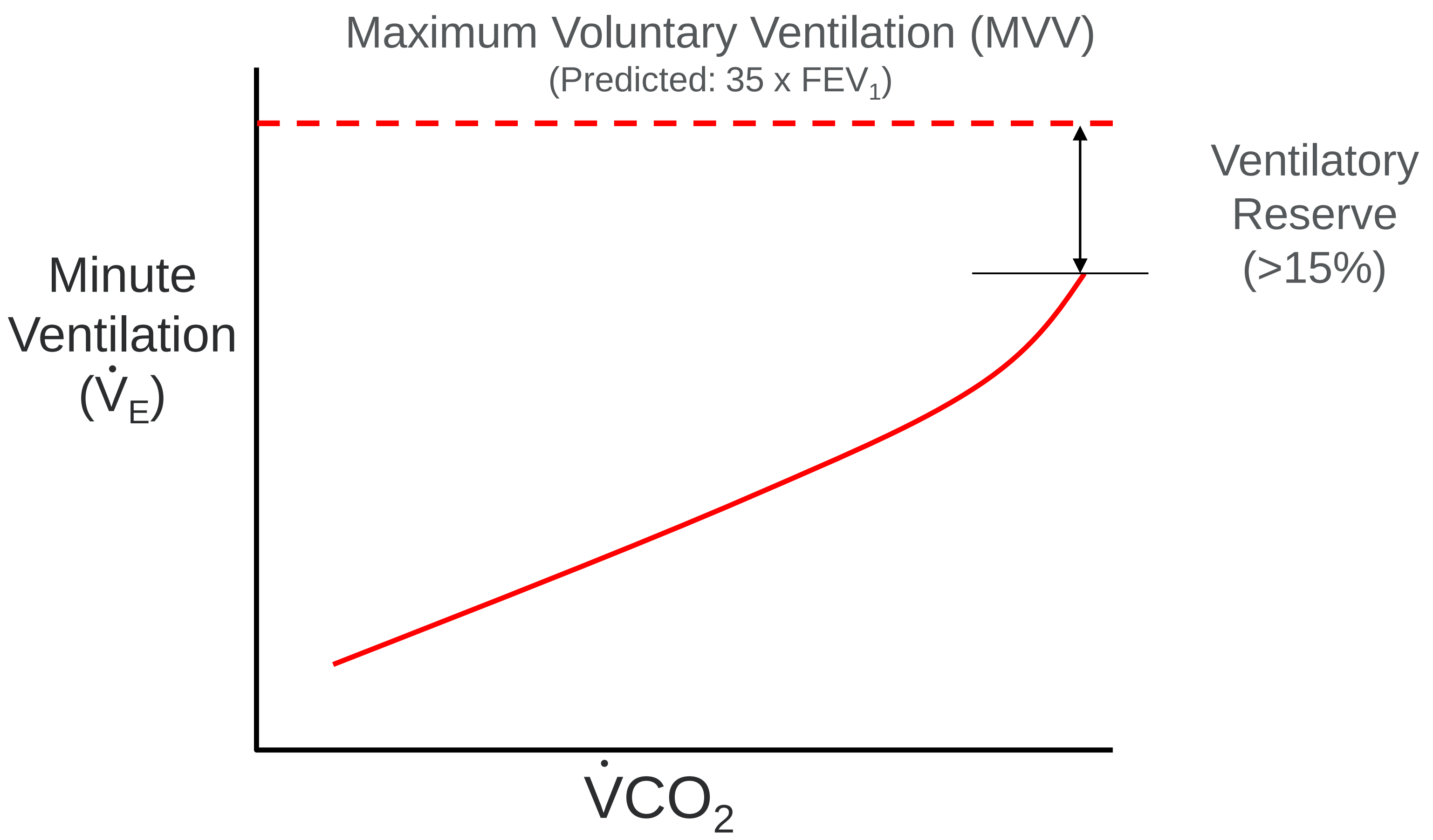
$P_{ET}O_2$ = Alveolar PO_2

In order to exercise you have to be able to ventilate!

Ventilatory Response to Exercise

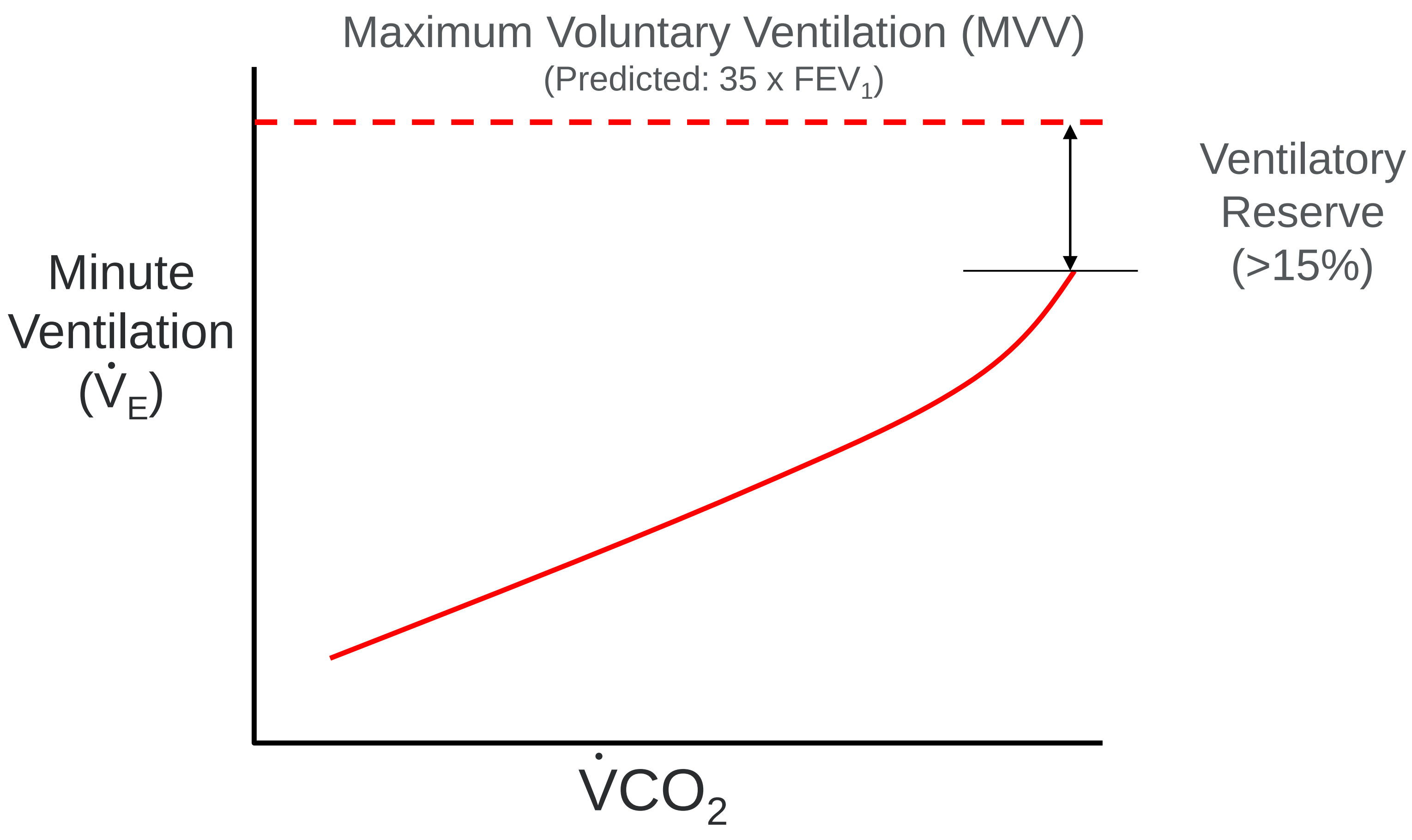


Ventilatory Response to Exercise



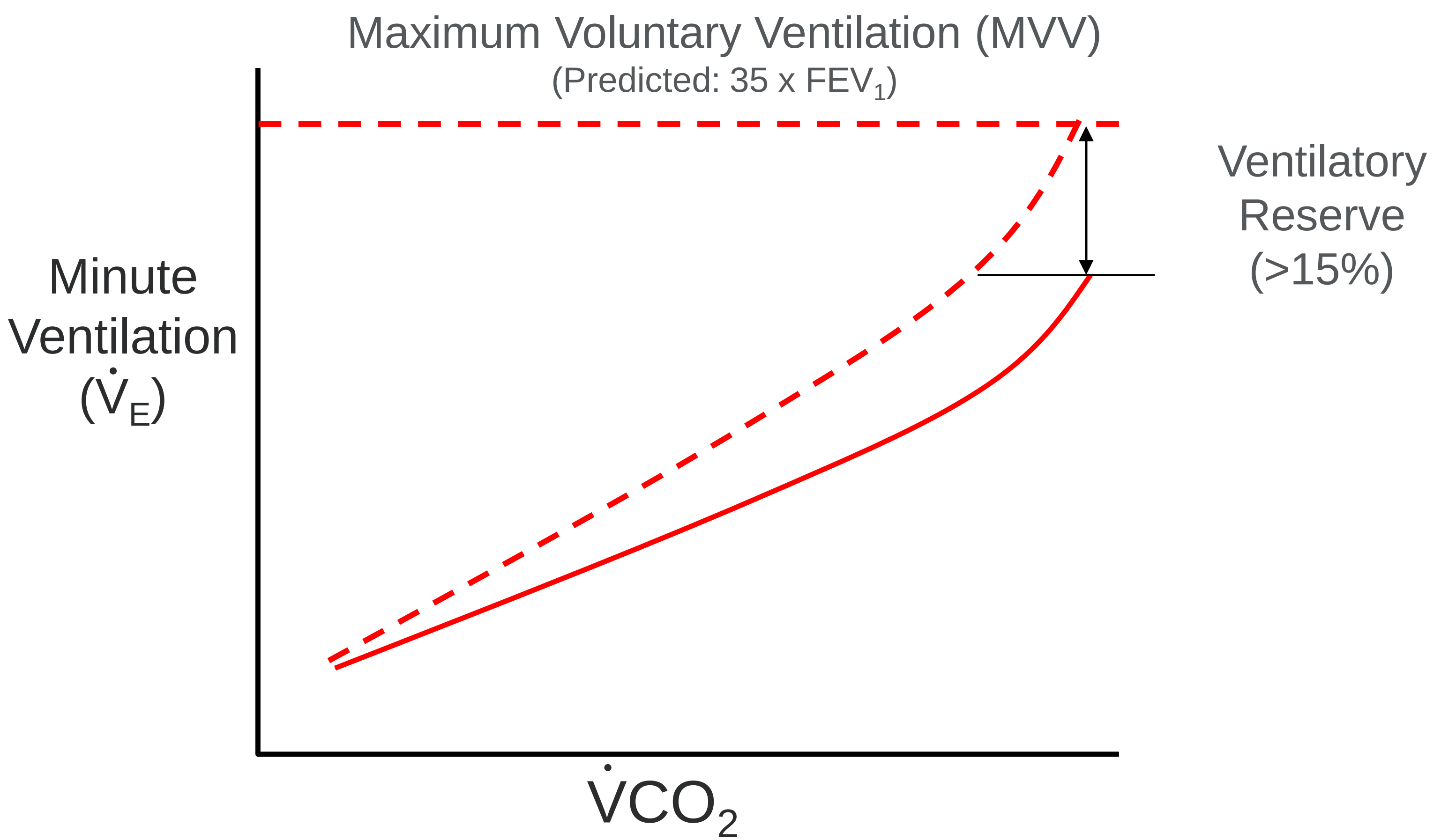
Ventilatory Response to Exercise

Capacity vs. Demand



Ventilatory Response to Exercise

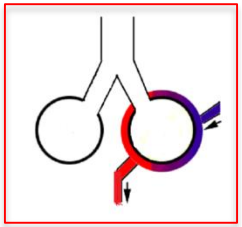
Capacity vs. Demand



Ventilatory Response to Exercise

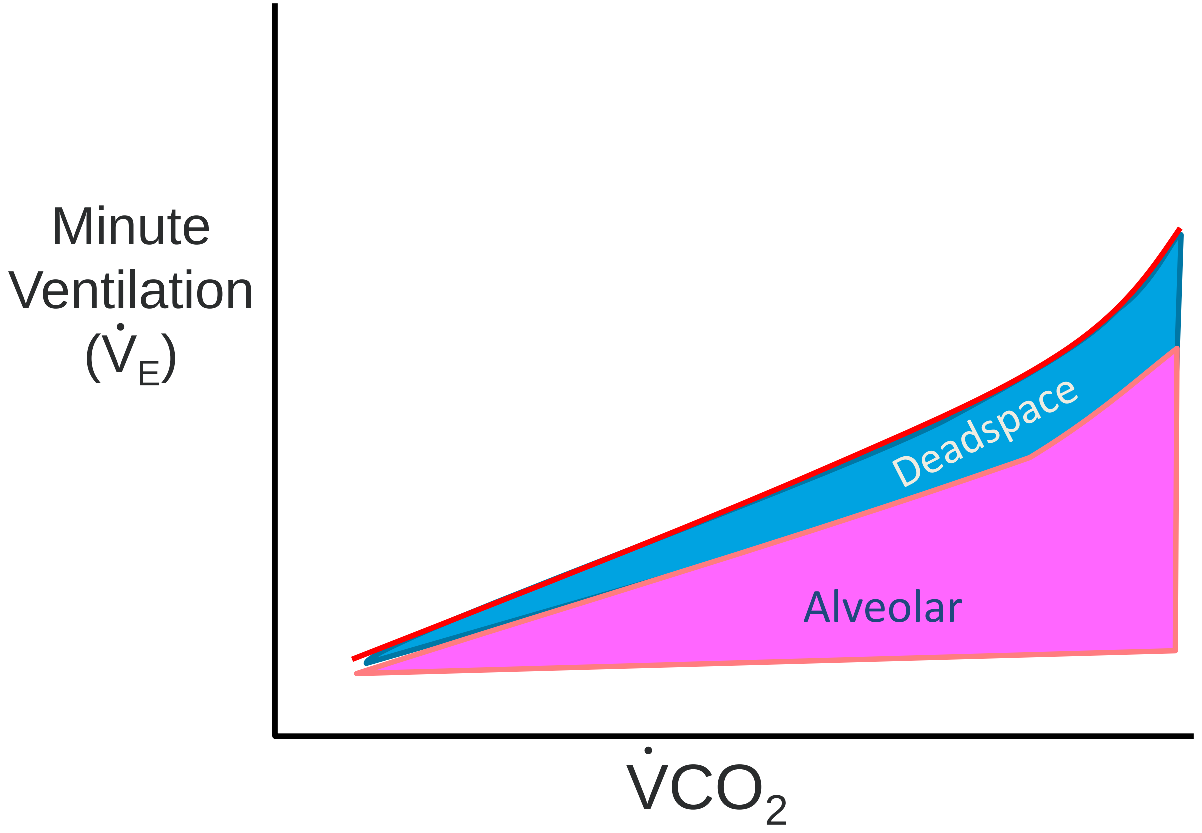
Minute Ventilation	=	Alveolar Ventilation	+	Deadspace Ventilation

$$\dot{V}_A \sim \frac{\dot{V}CO_2}{PaCO_2}$$



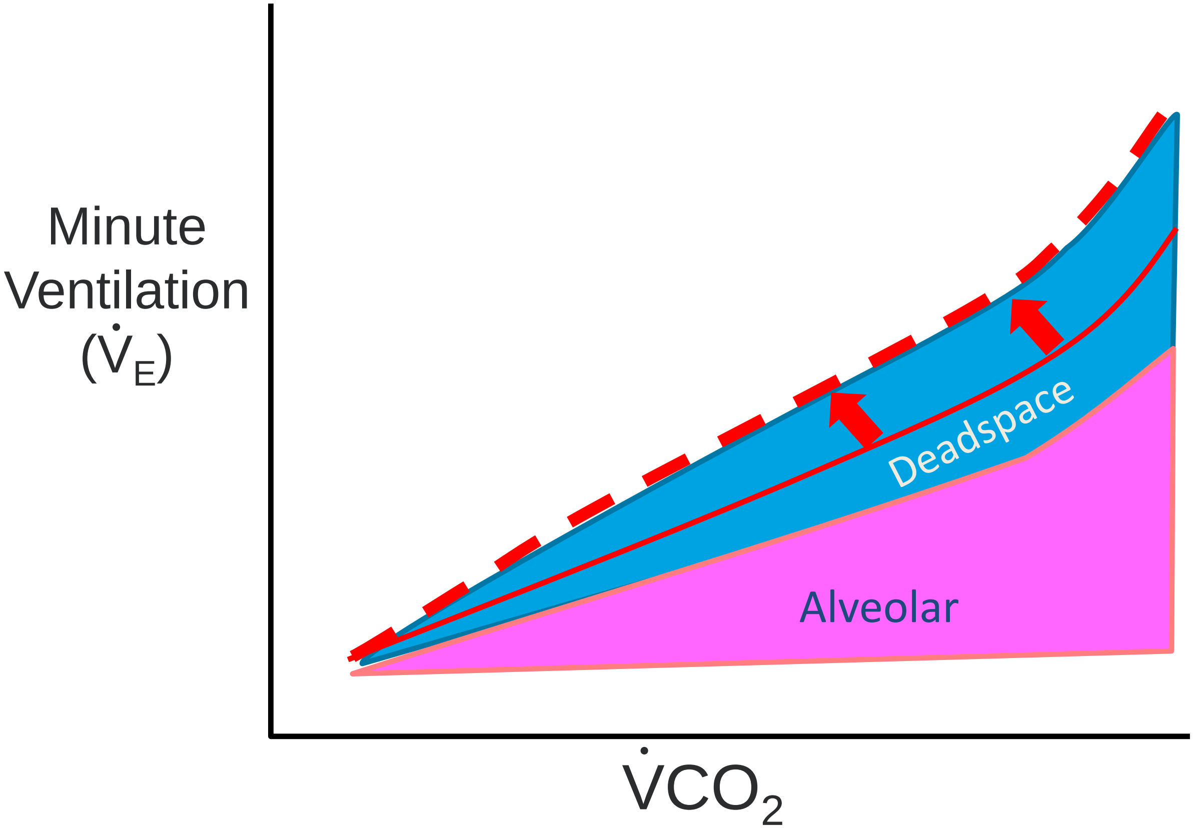
Ventilatory Response to Exercise

Minute Ventilation	=	Alveolar Ventilation	+	Deadspace Ventilation



High Deadspace

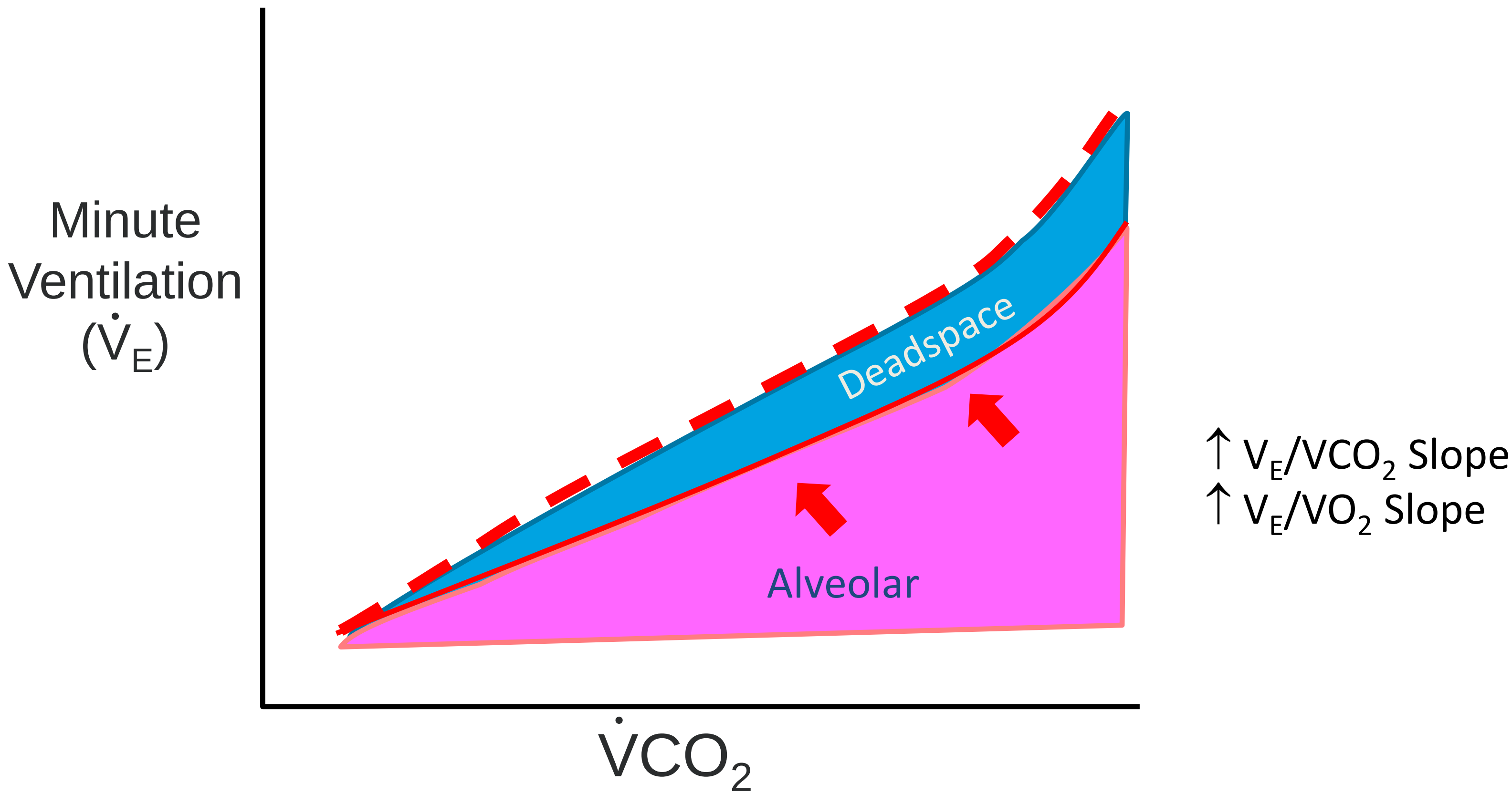
Minute Ventilation = Alveolar Ventilation + **Deadspace Ventilation**



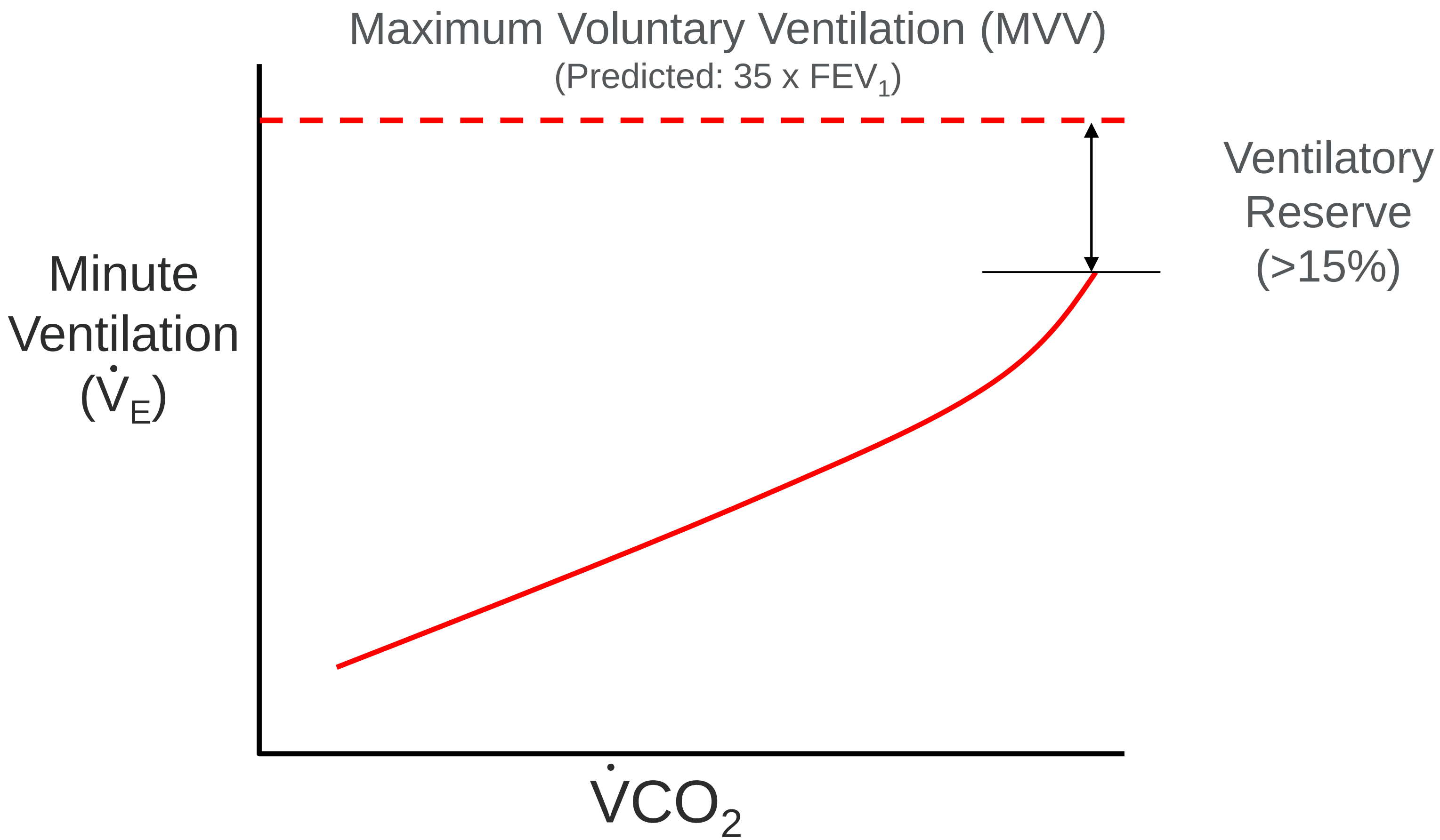
↑ V_E/VCO_2 Slope
↑ V_E/VO_2 Slope

High Alveolar Ventilation

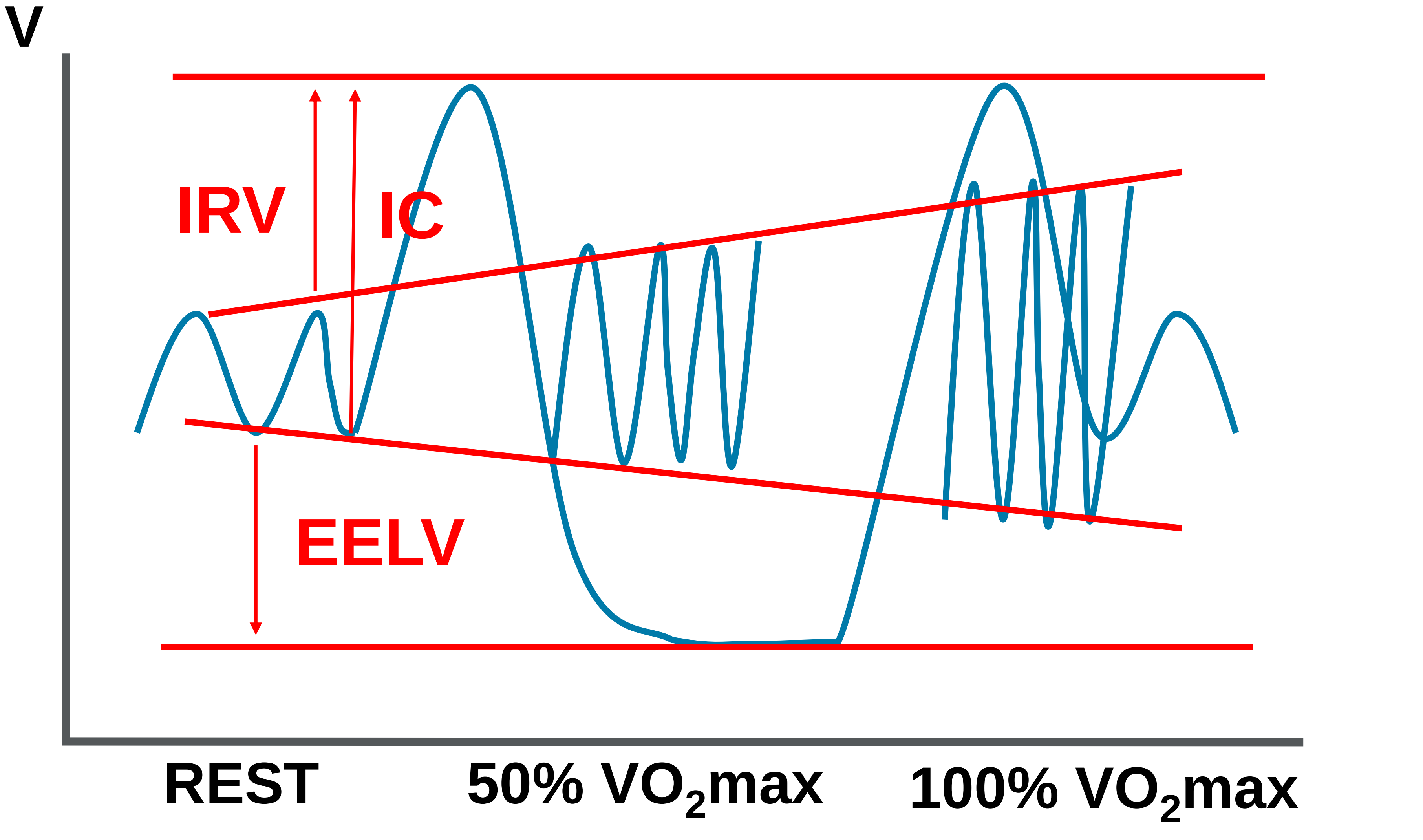
Minute Ventilation	=	Alveolar Ventilation	+	Deadspace Ventilation



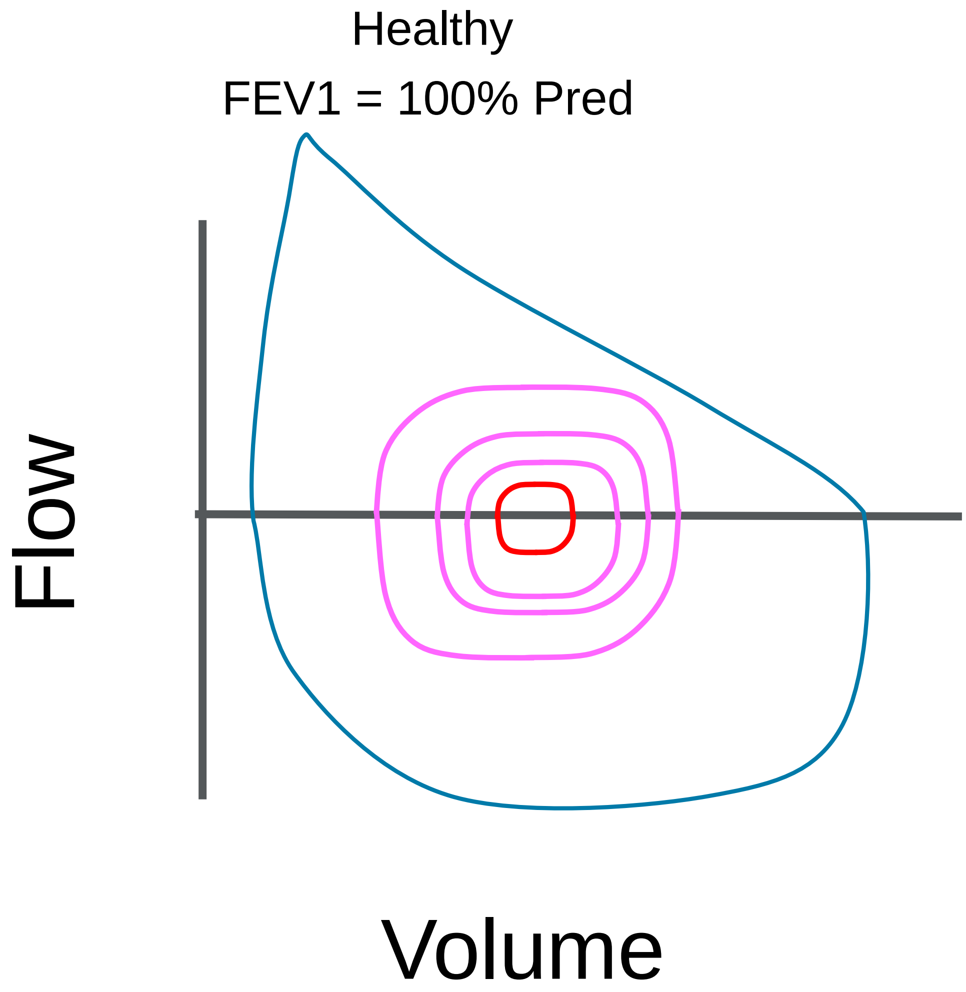
Ventilatory Response to Exercise



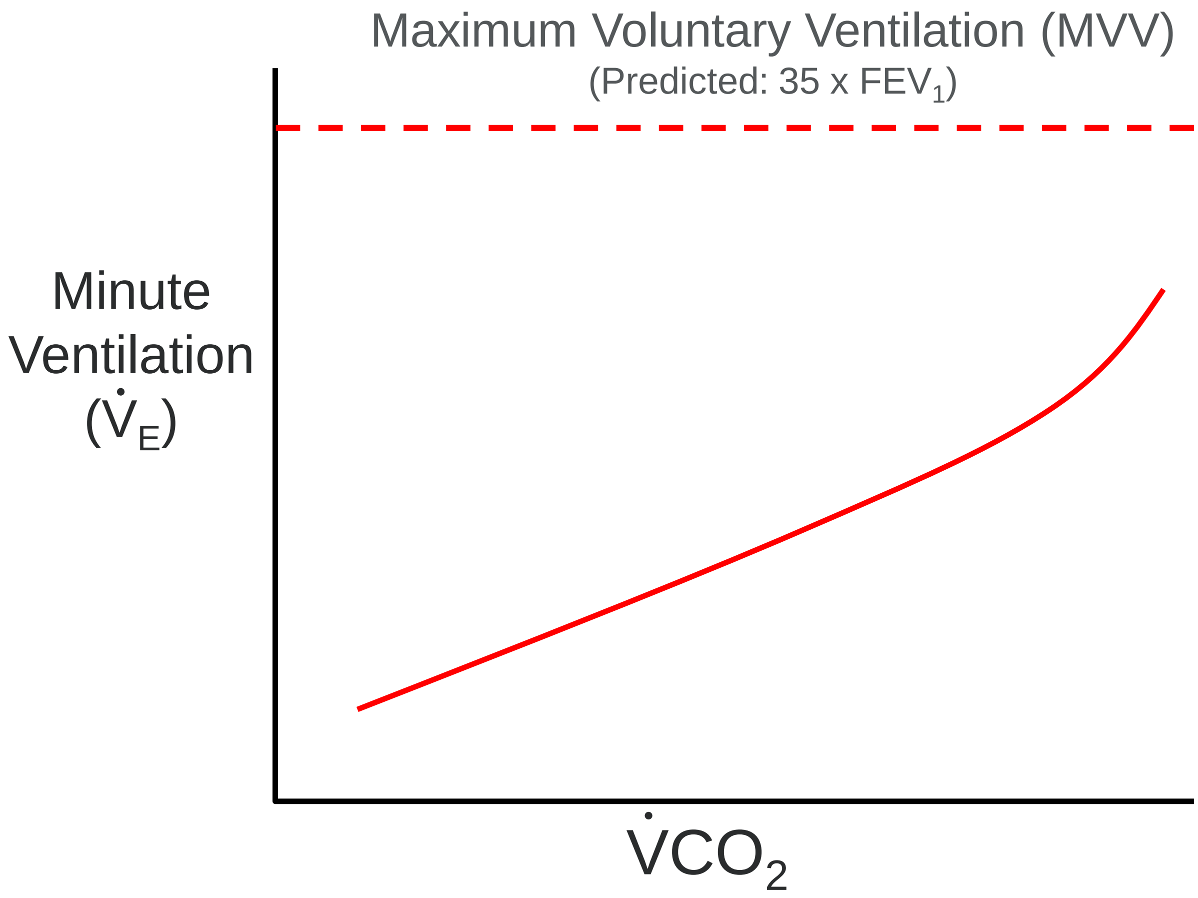
Lung Volumes During Exercise



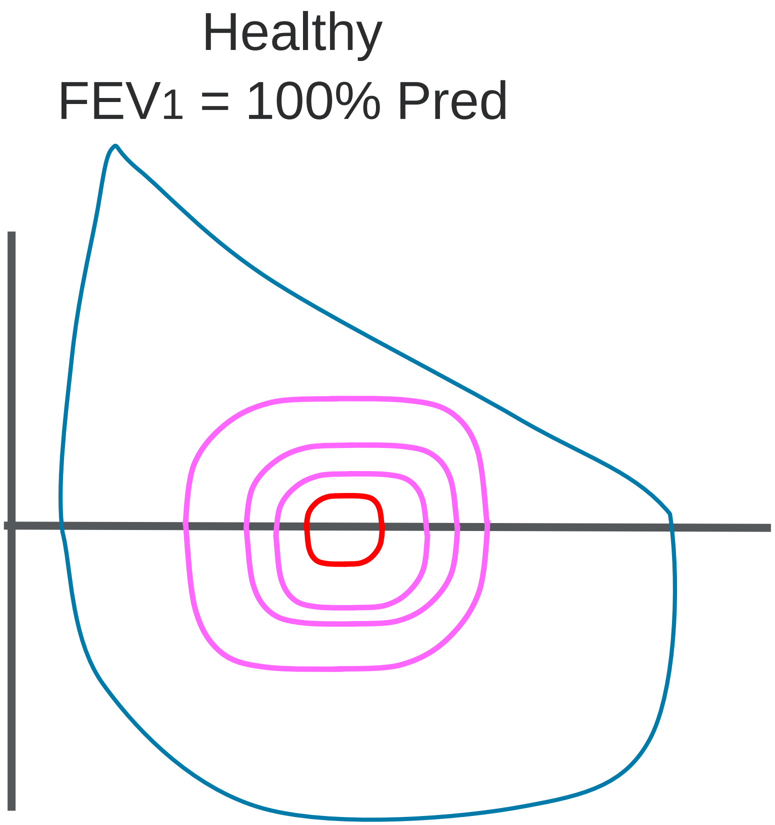
Tidal Volume & Resp Response to Exercise

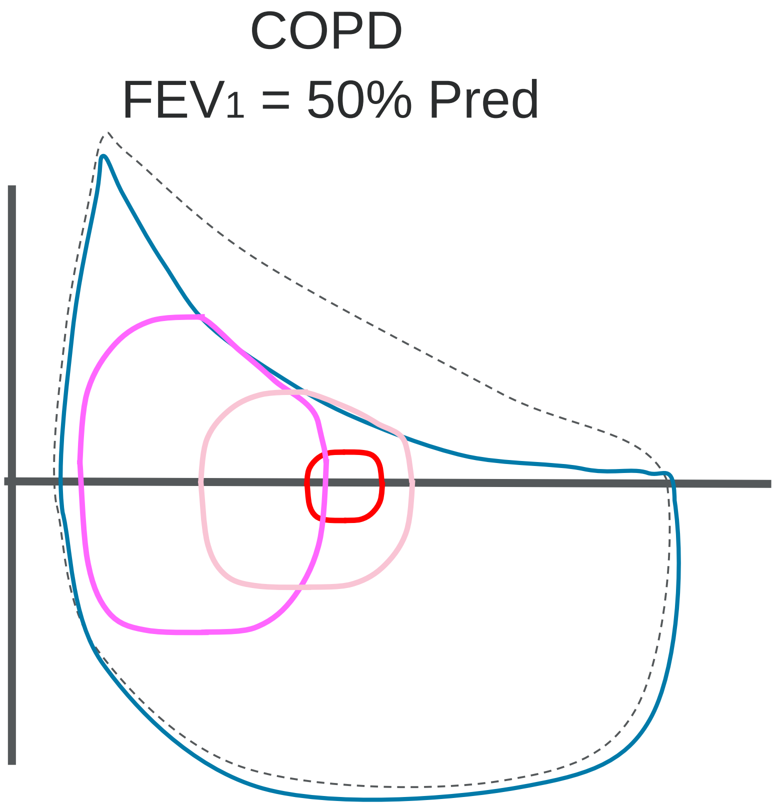


Ventilatory Response to Exercise

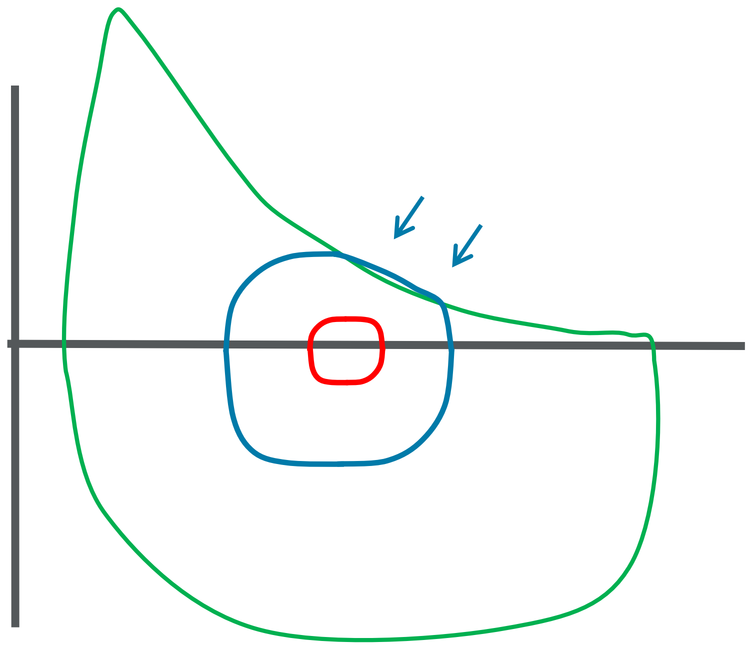


Expiratory Flow Limitation & Dynamic Hyperinflation





Expiratory Flow Limitation:

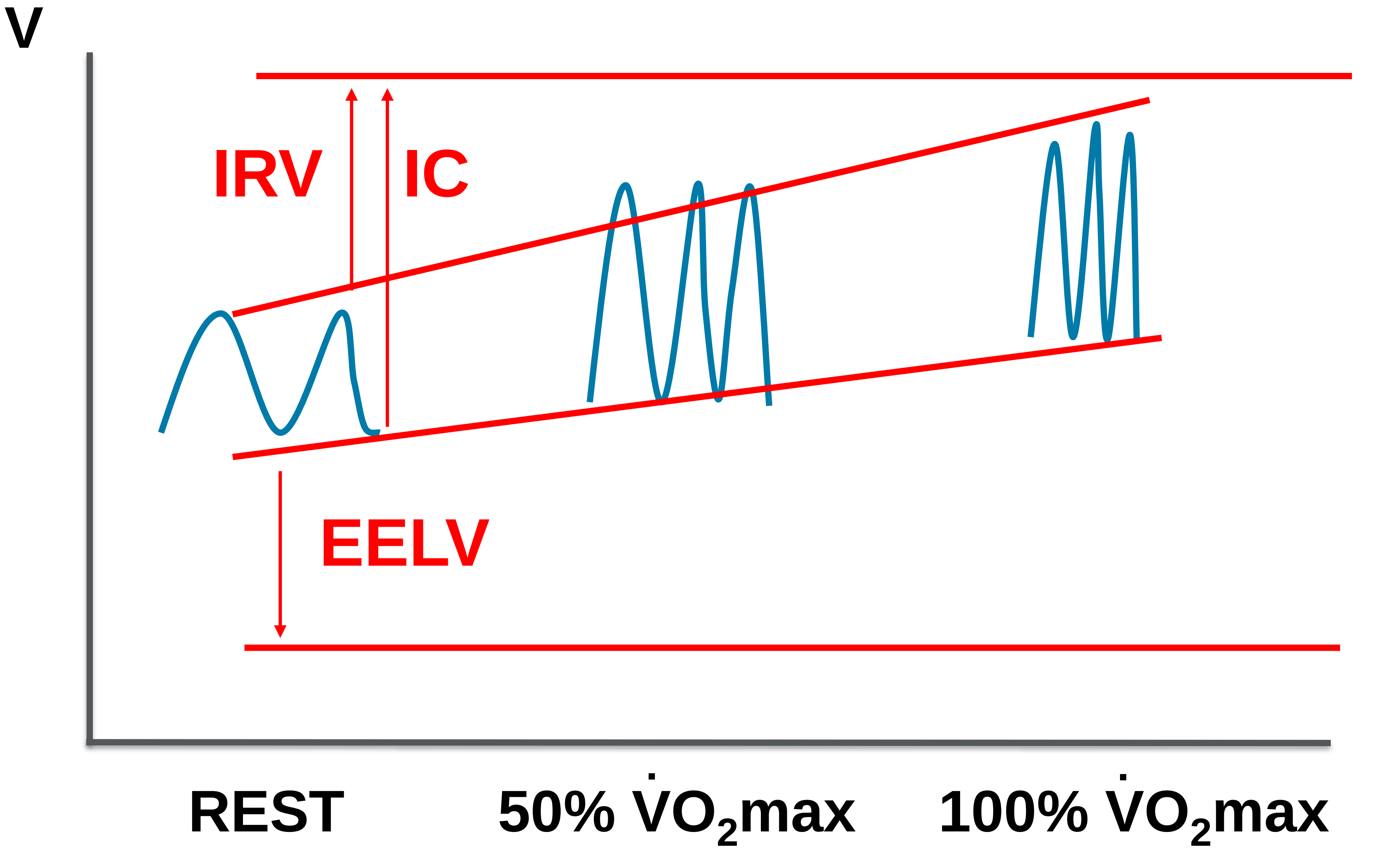


Promotes:

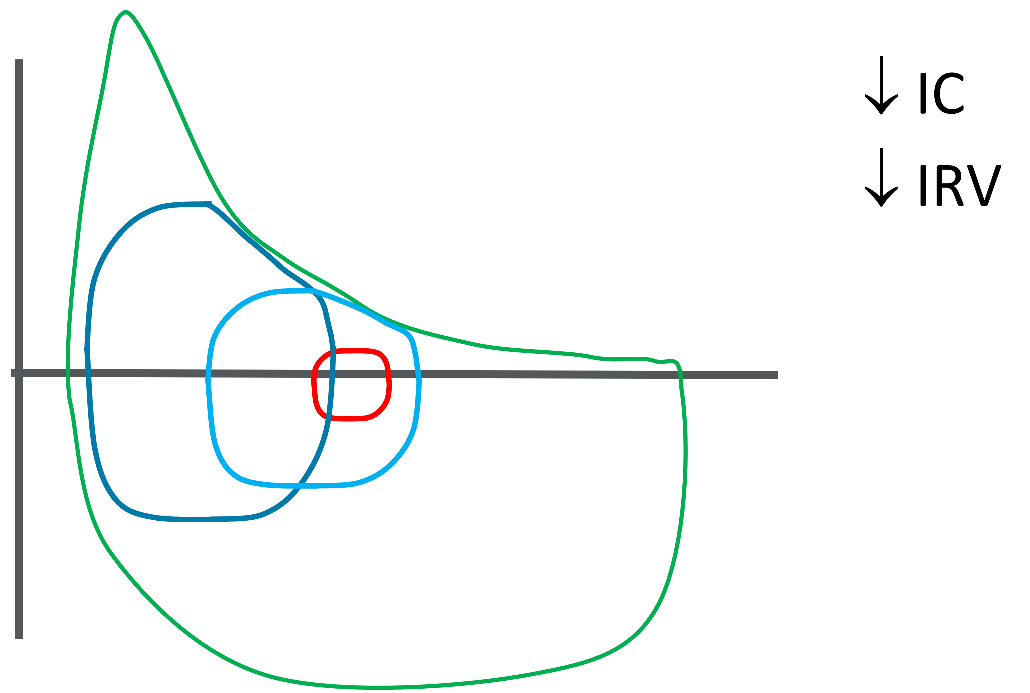
1. Increased work of breathing
2. Increased sensations of dyspnea
3. Dynamic hyperinflation

(Calverley & Koulouris, Eur Respir J 2005; O'Donnell & Laveneziana Eur Respir J 2006)

Dynamic Hyperinflation



EFL & Dynamic Hyperinflation:

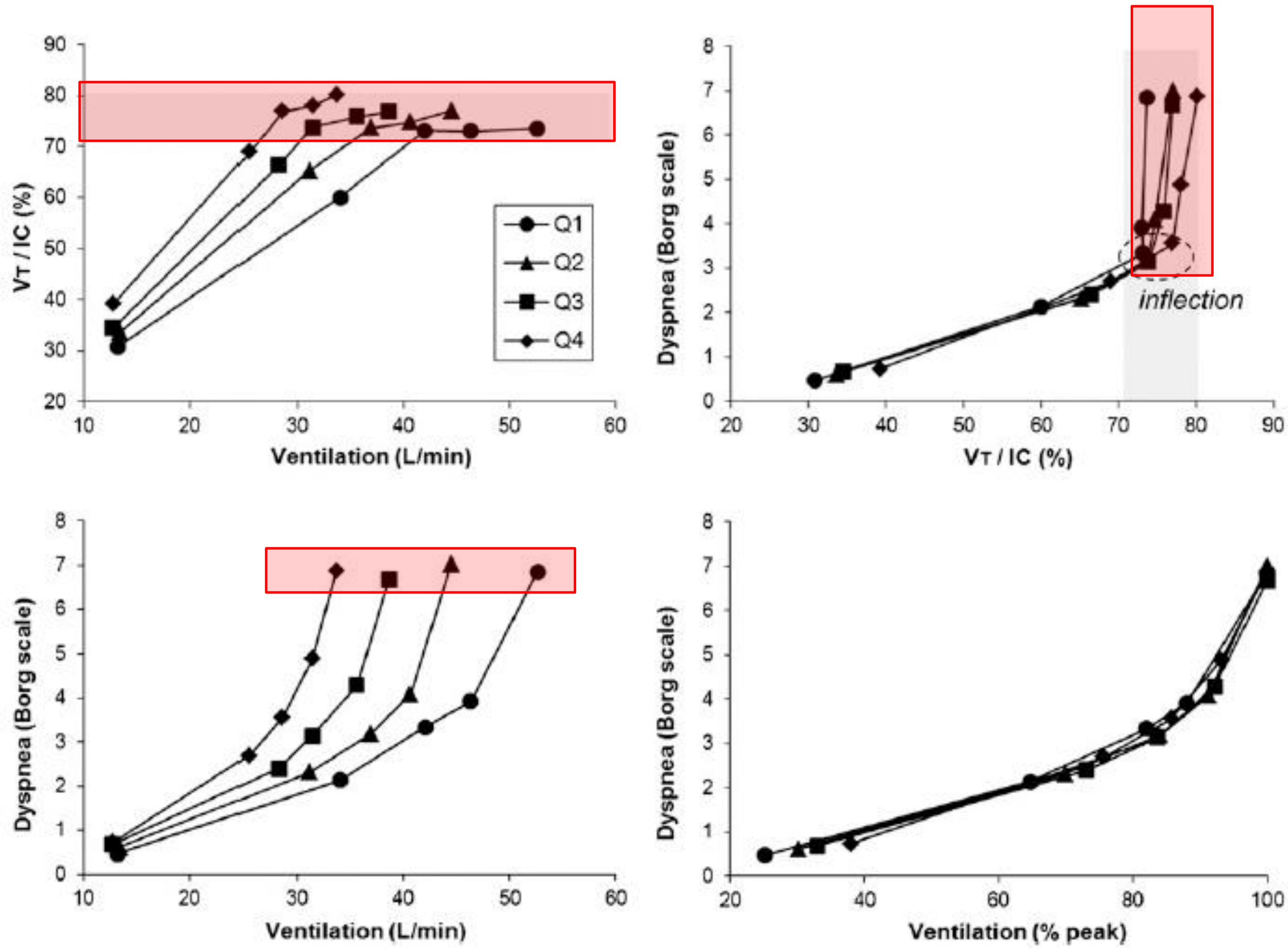


Promotes:

1. Increased elastic work of breathing
2. Functional inspiratory muscle weakness by shortening diaphragm
3. Reduced ability of tidal volume to expand appropriately
4. Hypoventilation

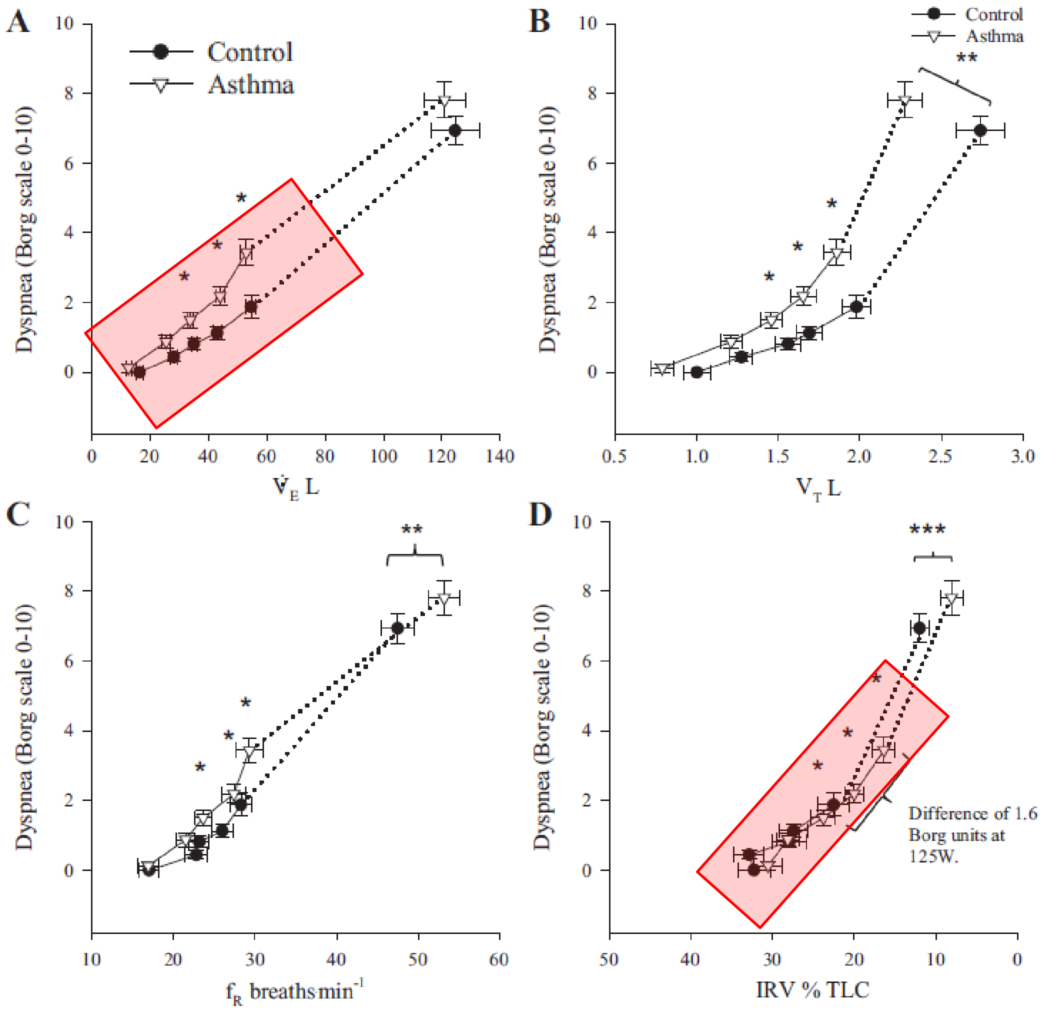
(O'Donnell & Laveneziana Eur Respir J 2006)

Exercise response in COPD



O'Donnell et al. CHEST 141(3):753–762, 2012

Exercise response in Asthma



Moore et al. J Appl Physiol, *In-Press*

American Thoracic Society/
American College of Chest Physicians

ATS/ACCP Statement on Cardiopulmonary Exercise Testing

This Joint Statement of the American Thoracic Society (ATS) and the American College of Chest Physicians (ACCP) was adopted by the ATS Board of Directors, March 1, 2002 and by the ACCP Health Science Policy Committee, November 1, 2001

Am J Respir Crit Care Med Vol 167. pp 211–277, 2003

Review Article

Assessing Exercise Limitation Using Cardiopulmonary Exercise Testing

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Pulmonary Medicine, pg 824091, 2012

STEP 1.

Was the test maximal?

1. Was RER ≥ 1.1?
2. HR > 90% predicted max?
3. Patient exhaustion/Borg >9/10?
4. Was there a plateau in $\dot{V}O_2$?
5. Was there evidence of a ventilatory limitation?

STEP 2.

Evaluation of $\dot{V}O_{2max}$ / $\dot{V}O_{2peak}$

STEP 3.

What was the exercise limitation(s)?

Cardiovascular

1. HR ~ max predicted
2. RER ≥ 1.1
3. Exhaustion
4. No Ventilatory limit
5. SpO_2 > 88%

Pulmonary

1. Vent Limitation:
   1. BR<15%
   2. Exp flow limitation
   3. Hyperinflation
2. SpO_2 ≤ 88%
3. Exhaustion
4. HR < max predicted
5. RER < 1.1

Other

1. Leg/Back Pain
2. CV Concern
   (i.e. ST depression etc)
3. Not exhausted
4. HR < max predicted
5. RER < 1.1

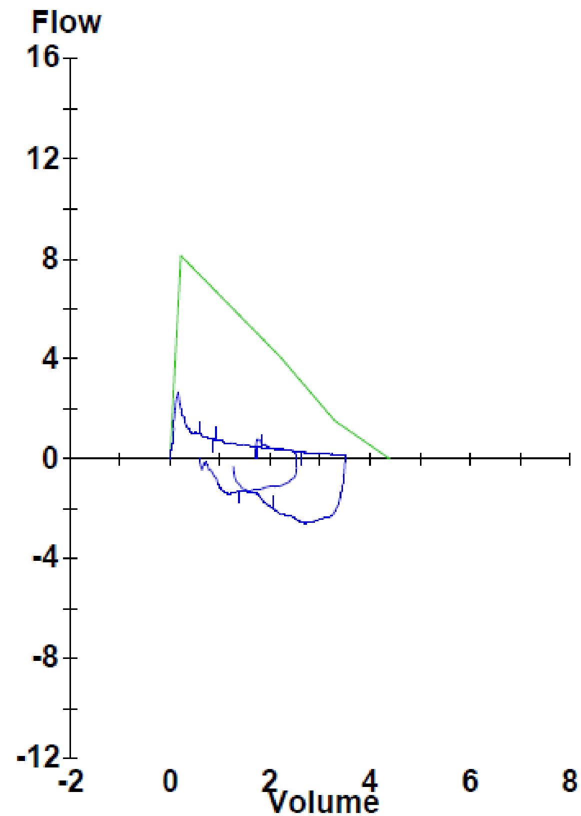
Clinical Examples

1. Very severe COPD
2. 9 year-old with Bronchopulmonary dysplasia (BPD)

Patient # 1
(Very Severe COPD)

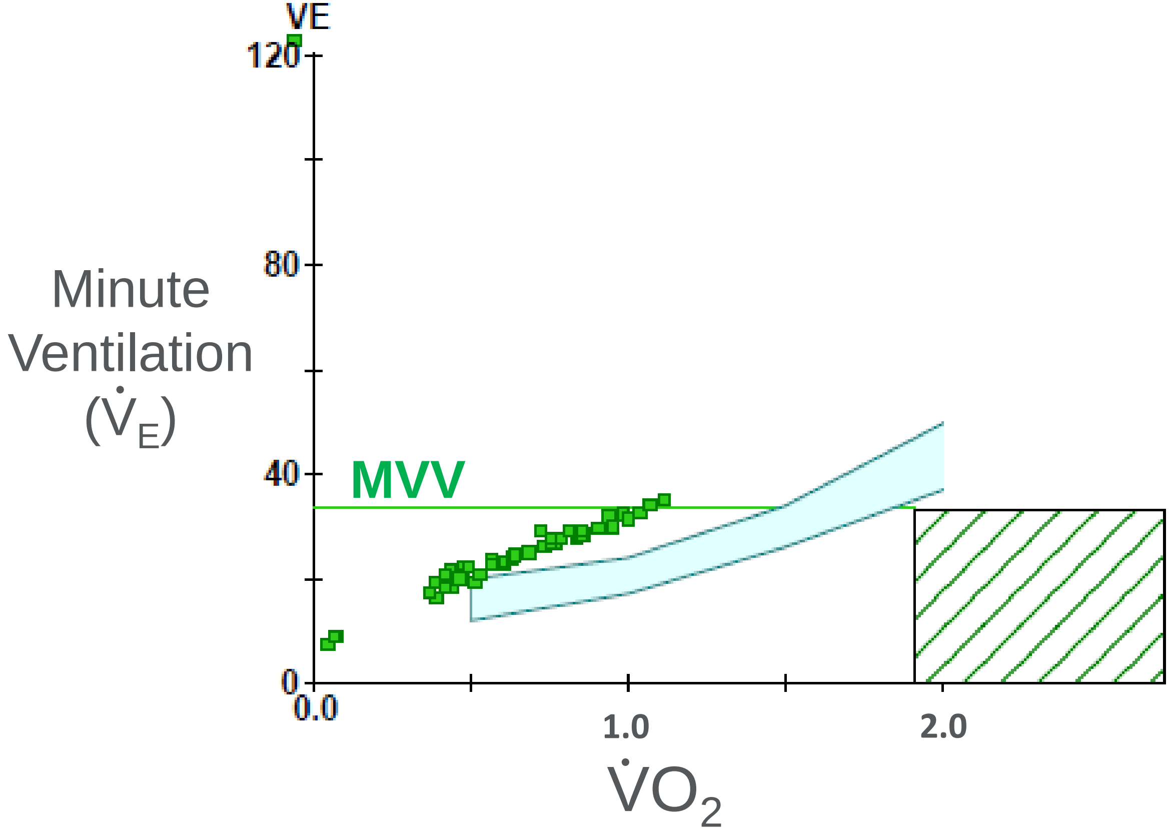
- 59 yr old male
- 40 pk year smoking history
- FEV_1 = 0.95L, 27%pred
- FVC = 3.51L, 80%pred
- Diffusion = 45%pred

- Max pt effort on CPET



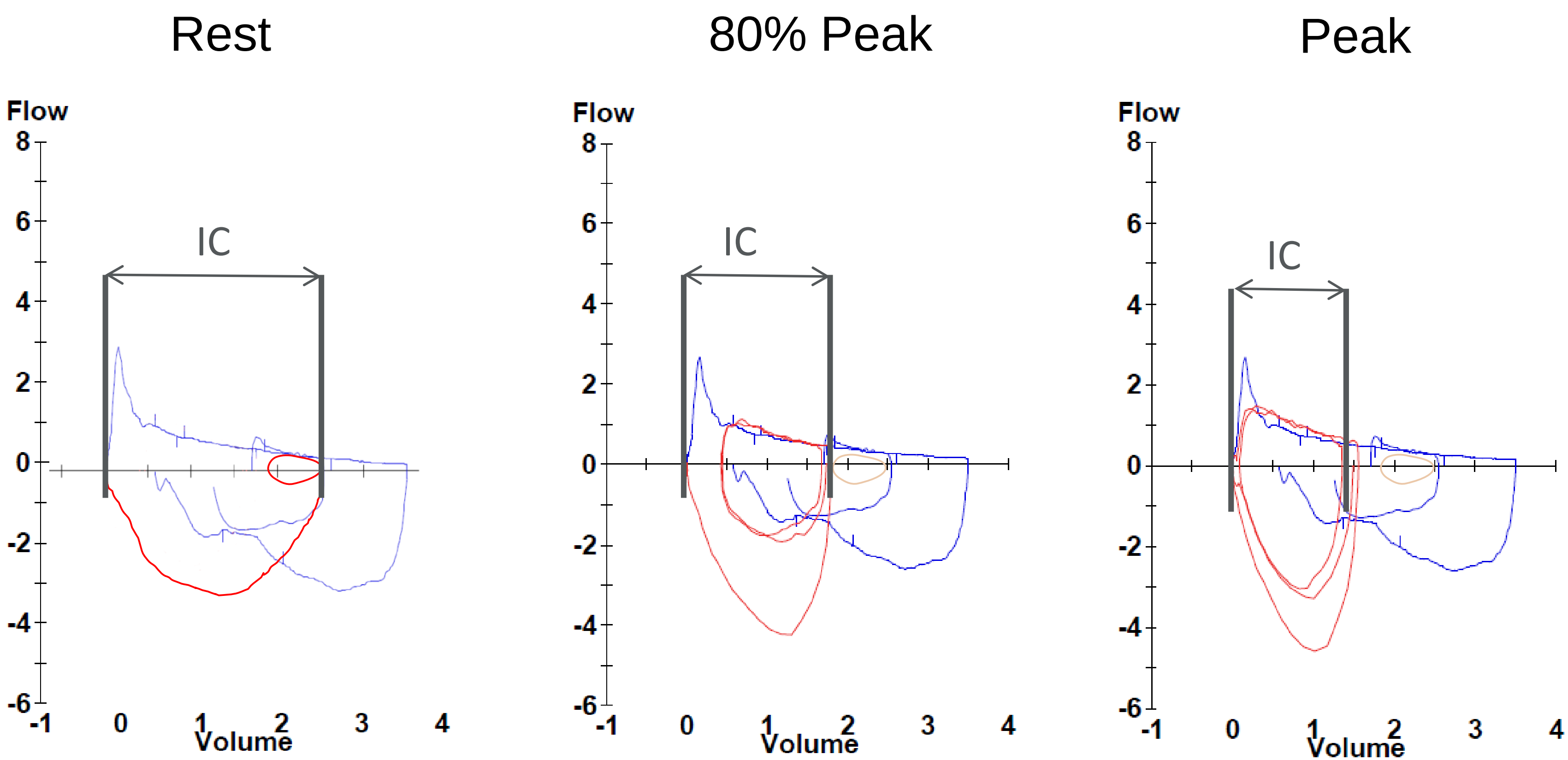
Peak Exercise Data

	Measured	Predicted
VO_{2peak} (ml/kg/min)	14	51%
RQ/RER	0.95	>1.1
Peak HR	134	84%
Peak V_E	35 L	33 L
Breathing Reserve	**-6%**	>15%
SpO_2	**85%**	>88%



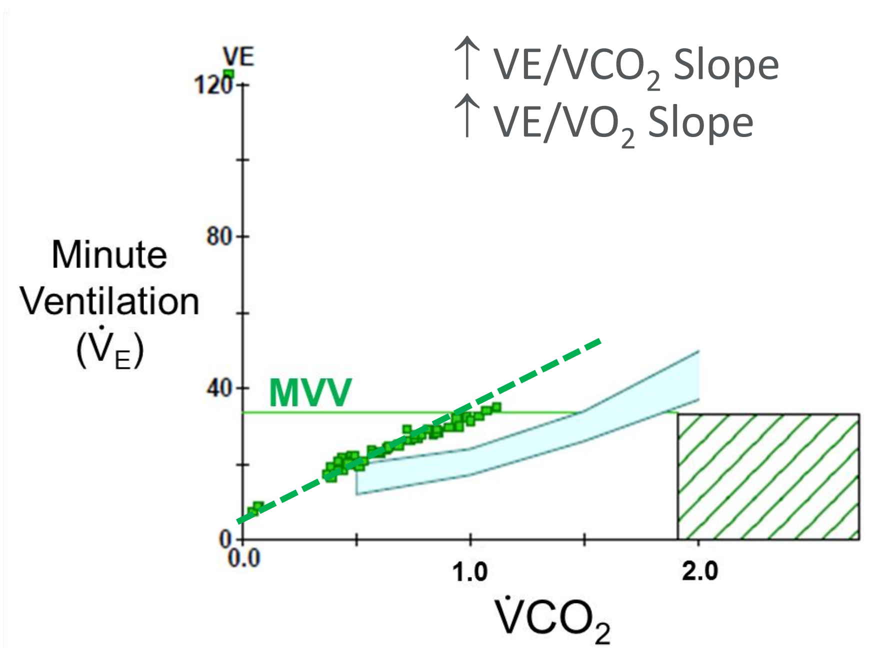
$\dot{V}_E$ @ peak > MVV $\therefore$ no Breathing Reserve

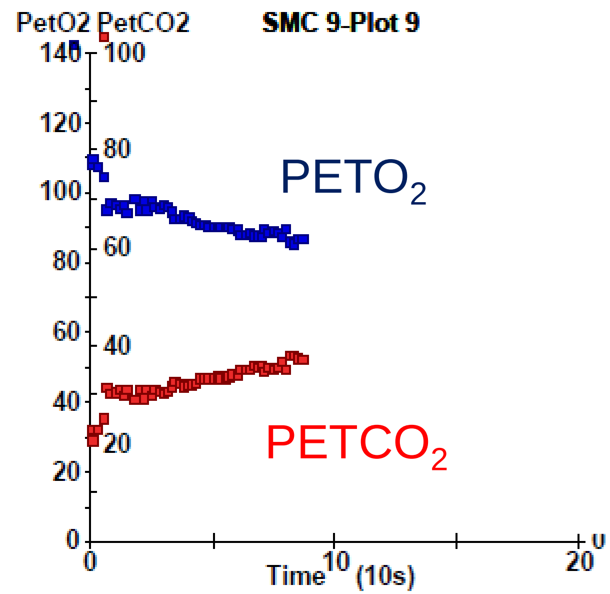
Operating Lung Volumes



- Expiratory flow limitation
- Progressive decrease in IC and IRV

Minute Ventilation = Alveolar Vent + Deadspace Vent





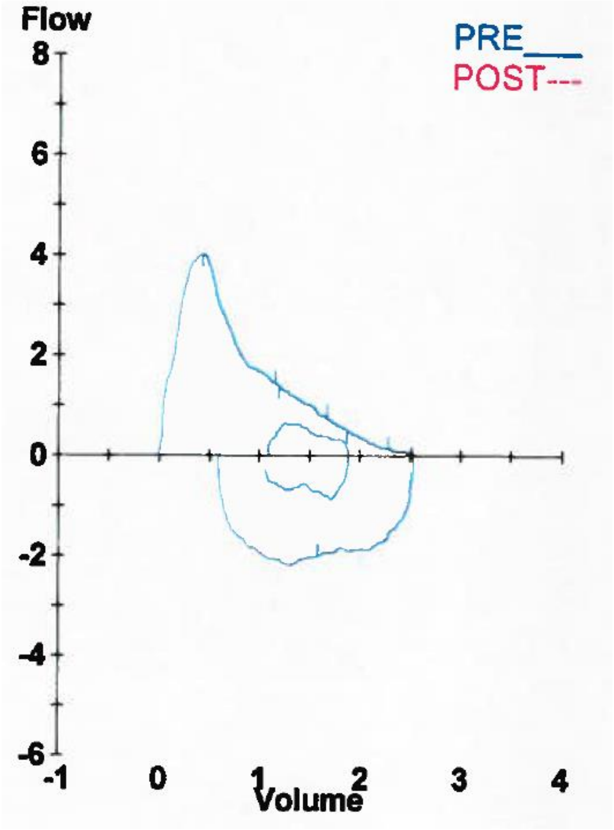
- $PETCO_2$ ***rises*** w/ exercise (~ 42 mmHg at peak) indicating *relative alveolar hypoventilation*

Patient # 2
(Bronchopulmonary Dysplasia)

- 9 yr old male
- Born 27 weeks gest age

  - Birth Weight 780g

- FEV_1 = 1.73, 80%pred
- FVC = 2.53, 106%pred
- Diffusion = 85%pred



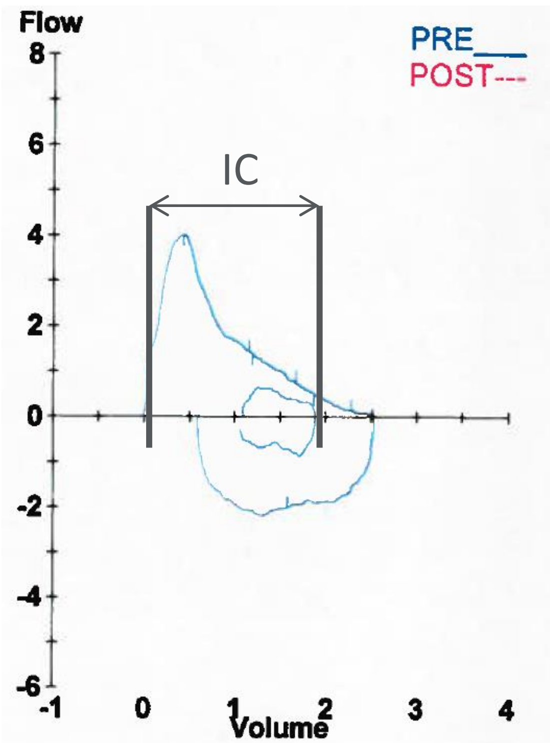
(MacLean et al. Thorax 2016)

Peak Exercise Data

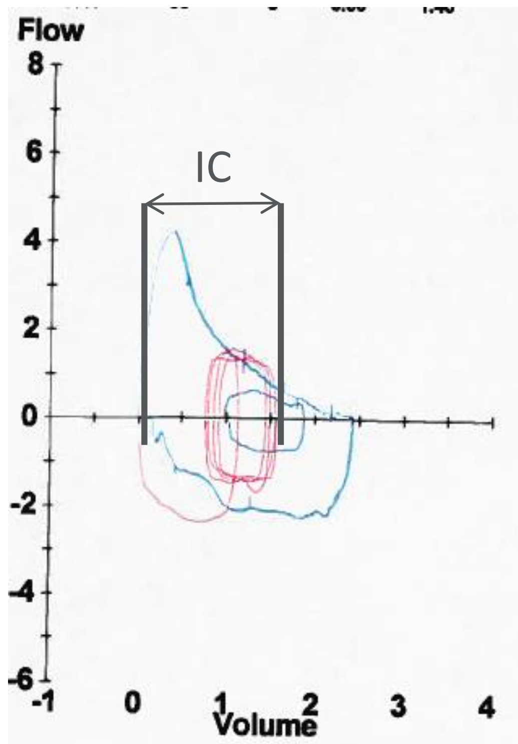
	Measured	Predicted
VO_{2peak}	33	60%
RQ/RER	0.95	>1.1
Max HR	163	77%
Max V_E	42 L	57 L
Breathing Reserve	26%	>15%
SpO_2	98%	>88%

Operating Lung Volumes

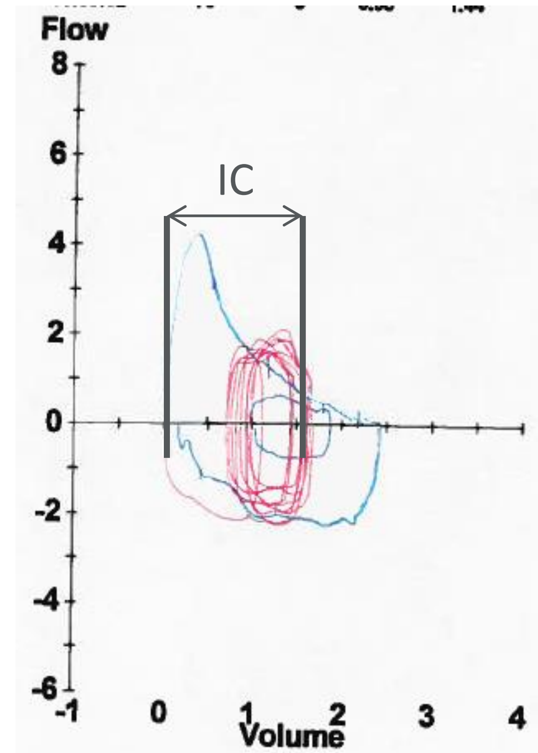
Rest



80% Peak



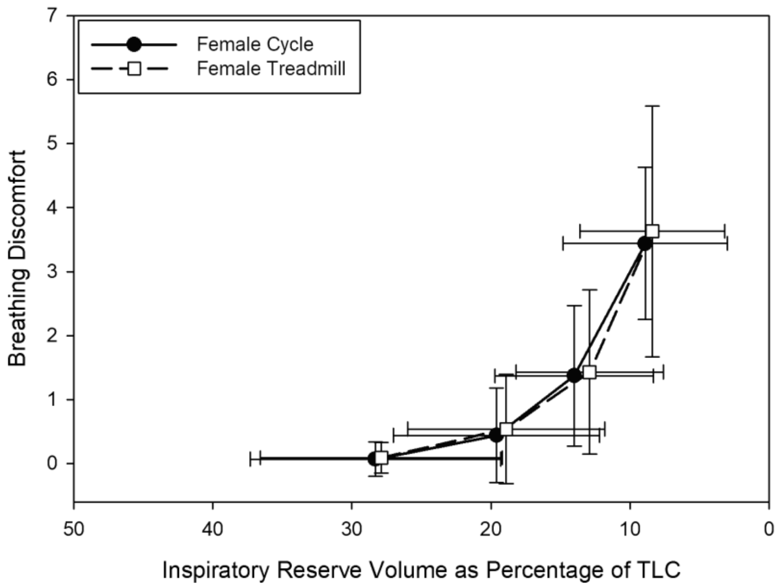
Peak



- Expiratory flow limitation
- Decrease in inspiratory capacity

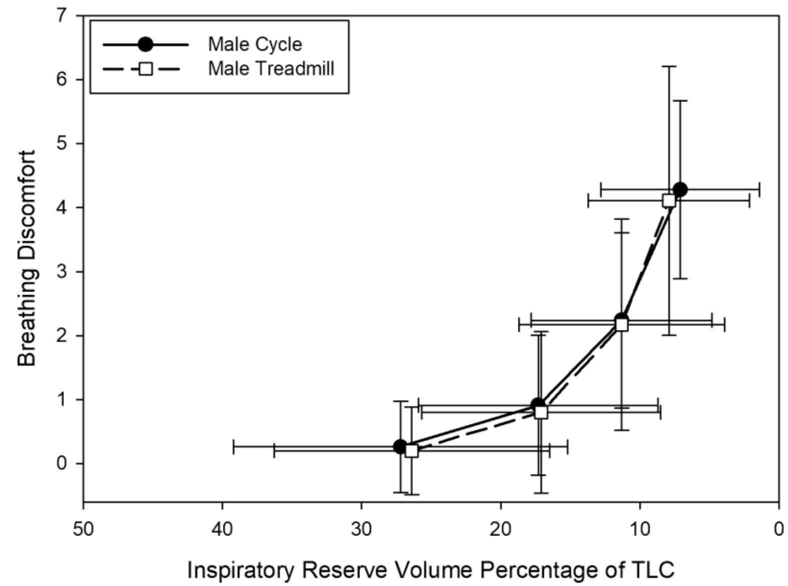
Sex & Modality differences?

Females



(FEV1: 65±17%pred, n = 27)

Males



(FEV1: 58±20%pred, n = 28)

(Holm et al. Resp Physiol Neurobiol 2014)

- VO_{2peak} ~ 2ml/kg/min (15%) greater on treadmill
- Similar respiratory/dyspnea response in COPD regardless of sex or exercise modality

Summary

Mechanisms for Dypnea:

1. Gas exchange
    1. Hypoxemia
2. Ventilation
    1. Breathing reserve < 15%
    2. Expiratory flow limitation
    3. Hyperinflation
    4. Hypoventilation

Contact information:

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Thank You