An introduction to CardioPulmonary Exercise Testing

Dr Rob Stephens

Google UCL Stephens

Talk Contents

- $\dot{V}O_2$ $\dot{V}Co_2$ AT VE/VCO2
- Run through a test
- Test Data
- Interpreting Test
- Associations
- Prehab – a bit!

Before
During
After

CPET: Why we test

Perioperative
Breathless – why?

Sport
‘Prehabilitation’
Other – transplant, disease monitoring etc

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

CPET: How to do a test

- Pretest: Hx, explain, contraindications
  Calibrate, Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

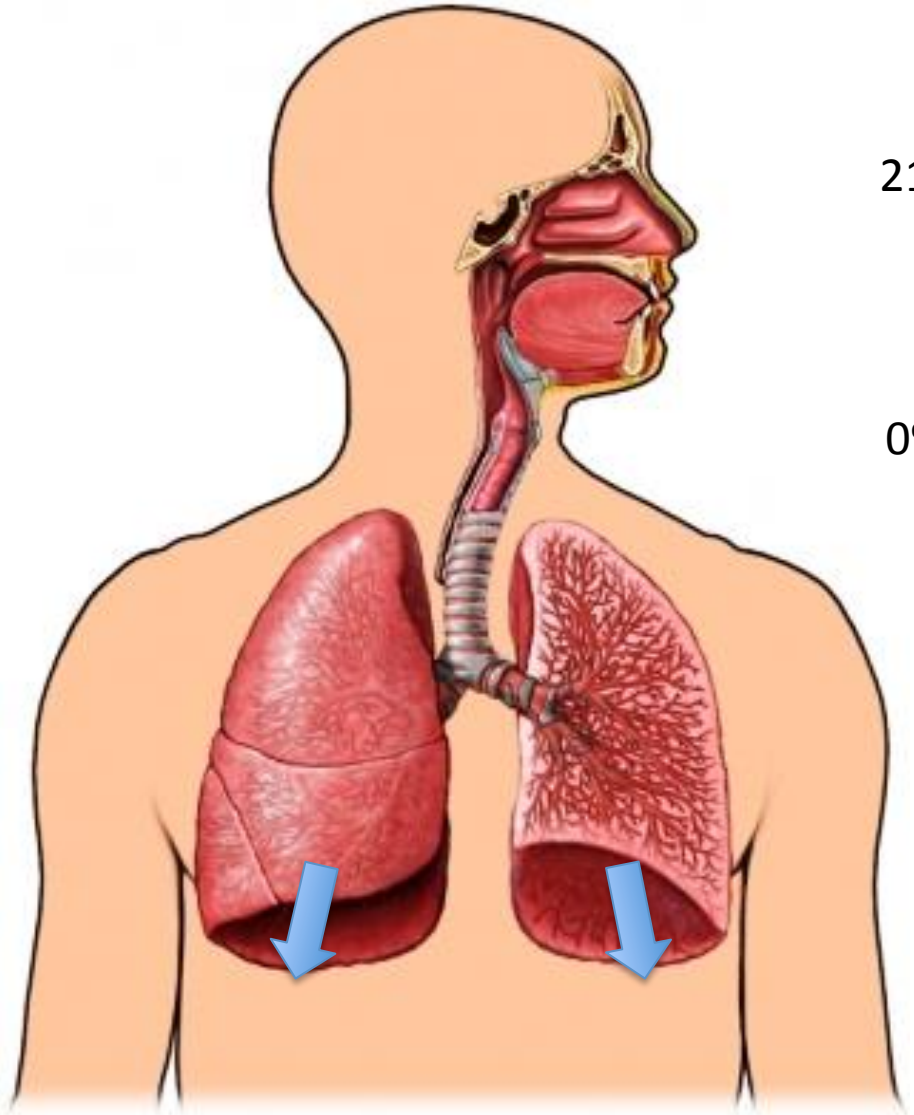
- Slowly increase resistance- according to how fit the patient is

- Stop when patient can go no more & record reason

- Wind- down

A tiny bit of physiology…

0_2 in, no CO_2 in



21% 0_2

0% $C0_2$

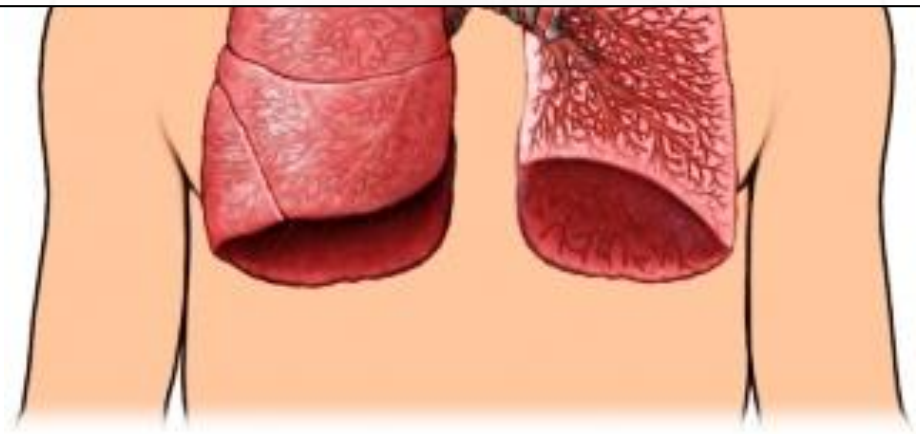
0_2 & CO_2 out

Aerobic Respiration: Carbohydrate

Glucose + Oxygen → Carbon Dioxide + Water

$C_6H_{12}0_6 + 60_2 \rightarrow 6CO_2 + 6H_20$

ADP + iP → **ATP**



0_2 & CO_2 out

0_2

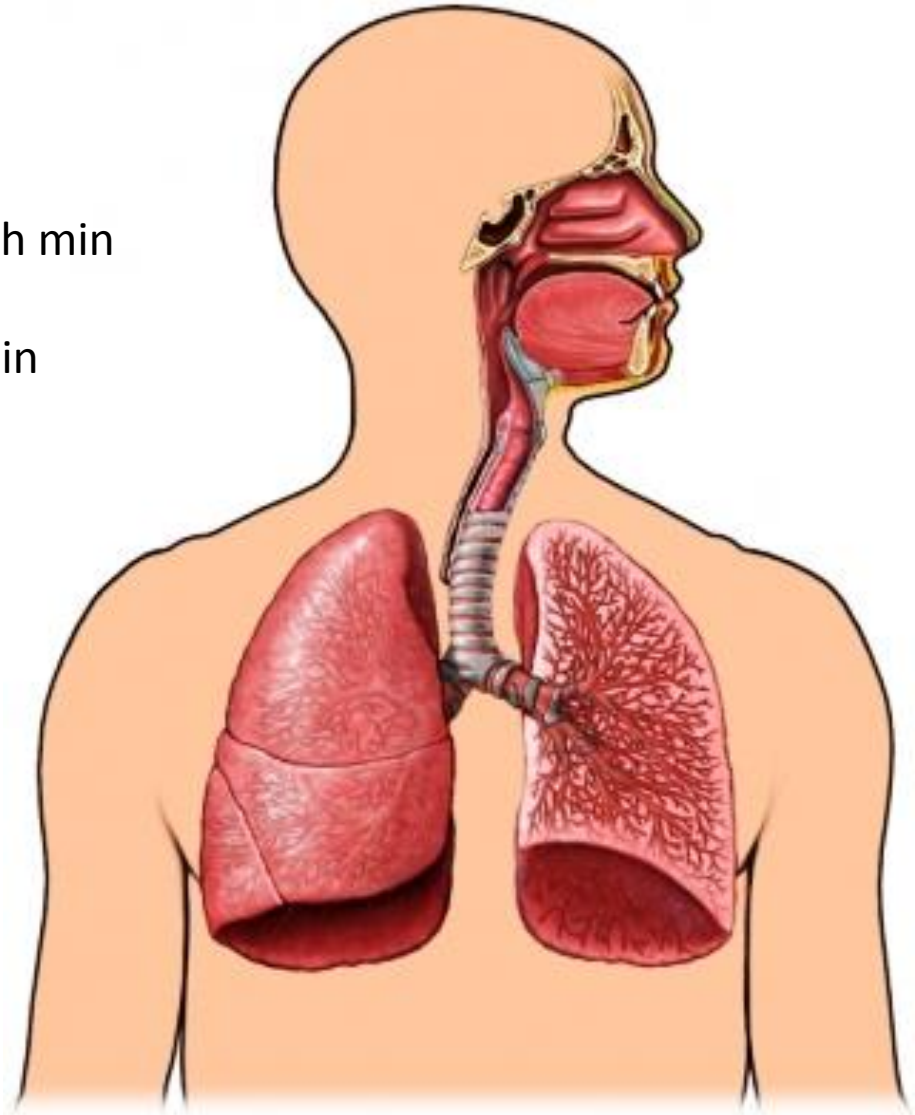
21% in

15% out

= 6%

Of 5000ml each min

=**$V0_2$** 300ml/min



RER

$$\frac{C0_2}{0_2}$$

$$\frac{250}{300}$$

c0.8

$C0_2$

0% in

5% out

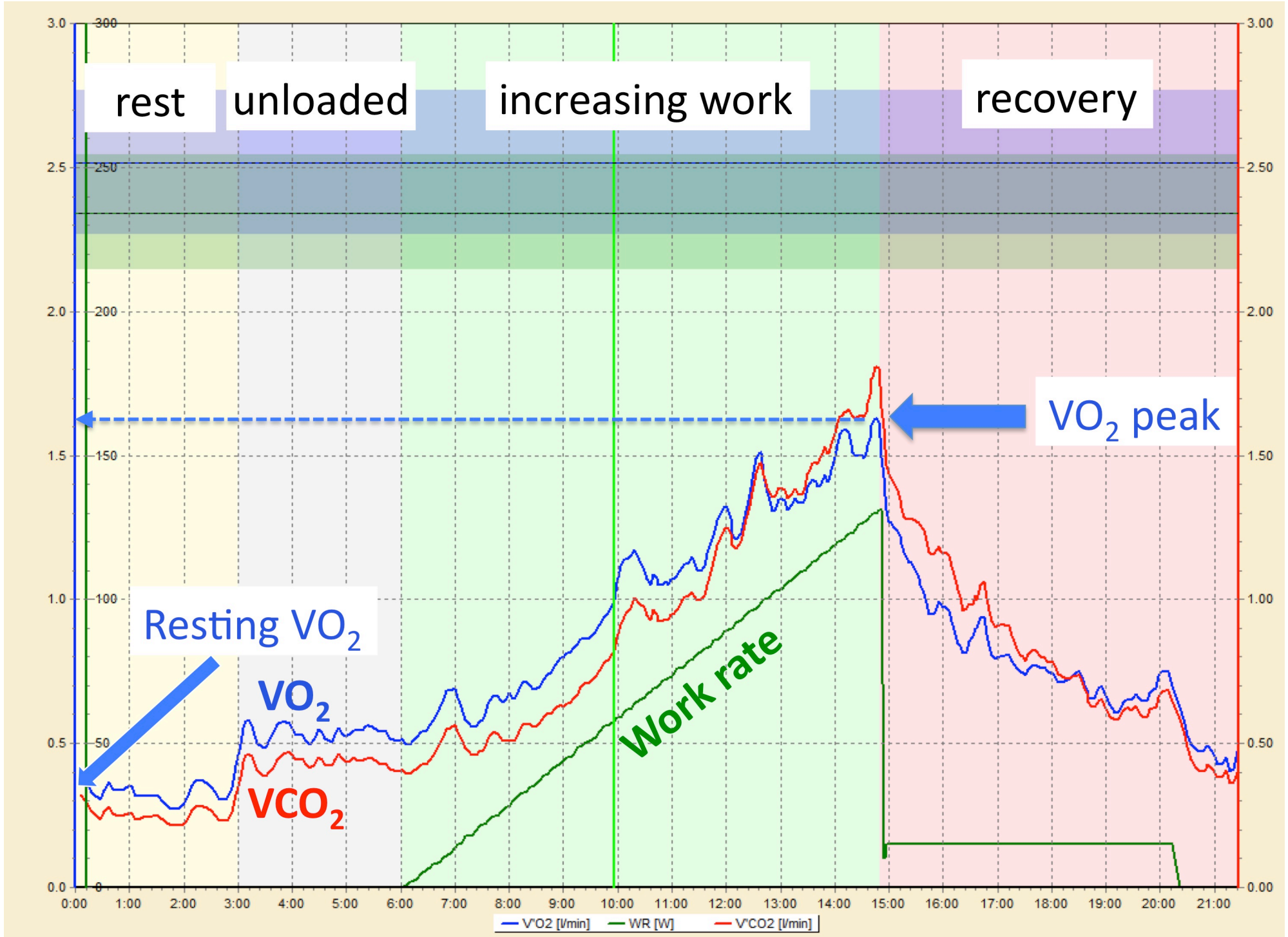
=5%

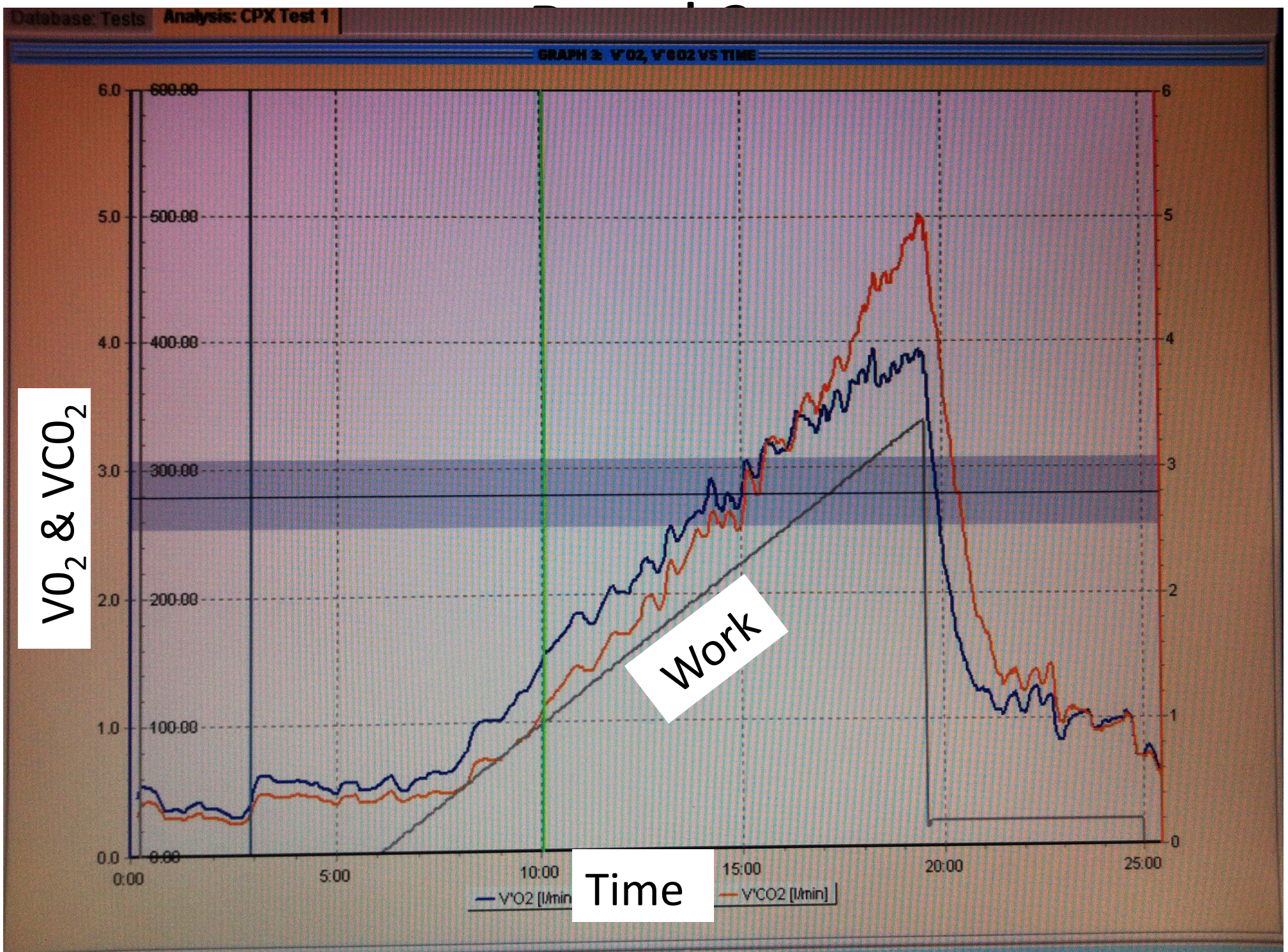
Of 5000ml a min

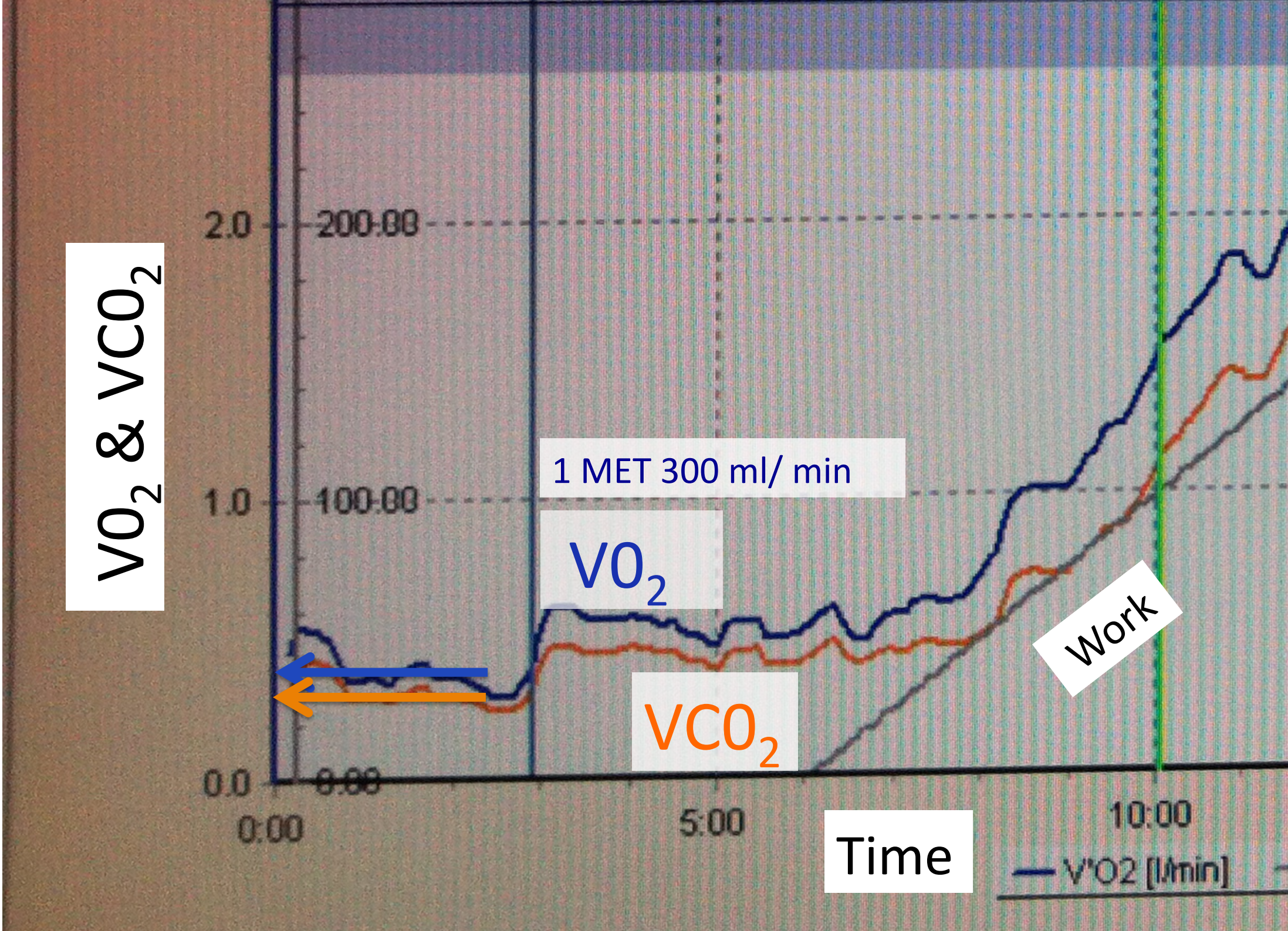
= **$VC0_2$** 250ml/min

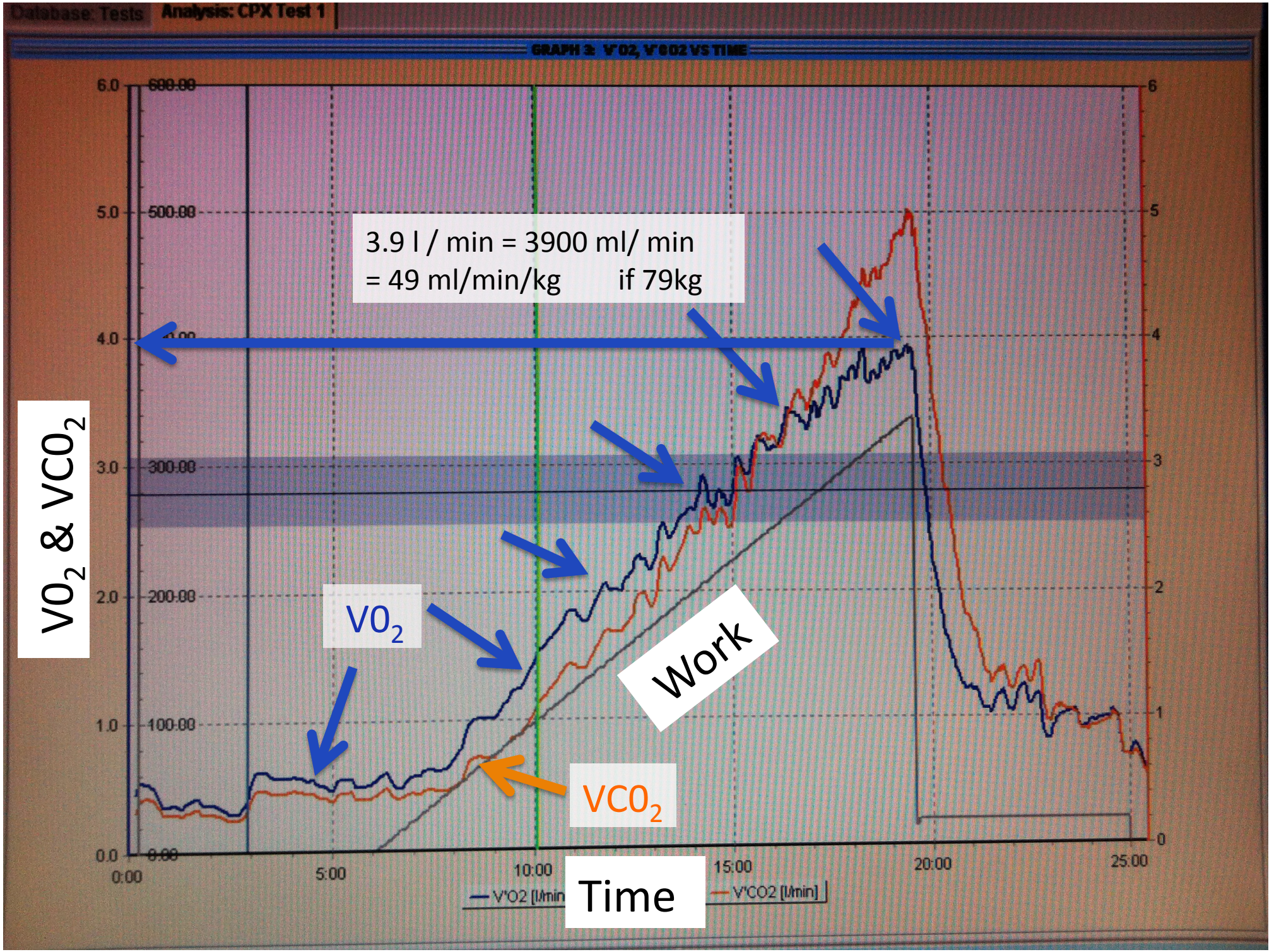
$V0_2$ & $VC0_2$

- Rest: 1 MET
- throughout increasing exercise
- at ‘Anaerobic Threshold’
- Peak- highest recorded
- **$V0_2$ peak l/min**
  - **ml/min/kg**


rest
unloaded
increasing work
recovery
VO_2 peak
Resting VO_2
VO_2
VCO_2
Work rate
V'O2 [l/min]
WR [W]
V'CO2 [l/min]


Database: Tests
Analysis: CPX Test 1
GRAPH 2: V'O2, V'CO2 VS TIME
6.0
5.0
4.0
3.0
2.0
1.0
0.0
600.00
500.00
400.00
300.00
200.00
100.00
0.00
6
5
4
3
2
1
0
0:00
5:00
10:00
15:00
20:00
25:00
V'O2 [l/min]
V'CO2 [l/min]
VO2 & VCO2
Work
Time

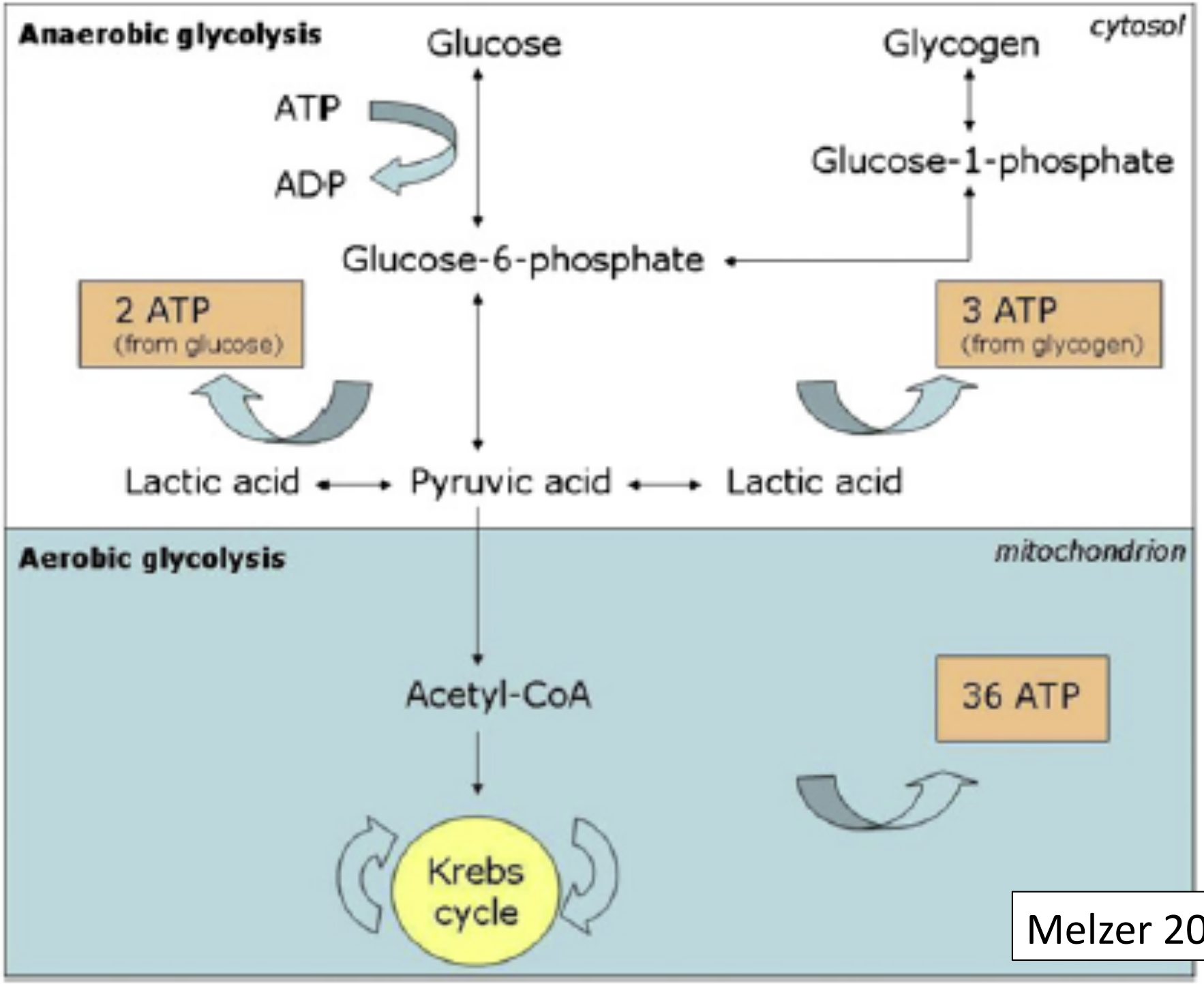

VO_2 & VCO_2
2.0
200.00
1.0
100.00
0.0
0.00
0:00
5:00
10:00
1 MET 300 ml/ min
VO_2
VCO_2
Work
Time
V'O2 [l/min]


Database: Tests
Analysis: CPX Test 1
GRAPH 2: V'O2, V'CO2 VS TIME
3.9 l / min = 3900 ml/ min
= 49 ml/min/kg if 79kg
VO2 & VCO2
VO2
VCO2
Work
Time
6.0
5.0
4.0
3.0
2.0
1.0
0.0
600.00
500.00
300.00
200.00
100.00
0.00
0:00
5:00
10:00
15:00
20:00
25:00
V'O2 [l/min]
V'CO2 [l/min]

VO_2 Peak

Anaerobic Threshold

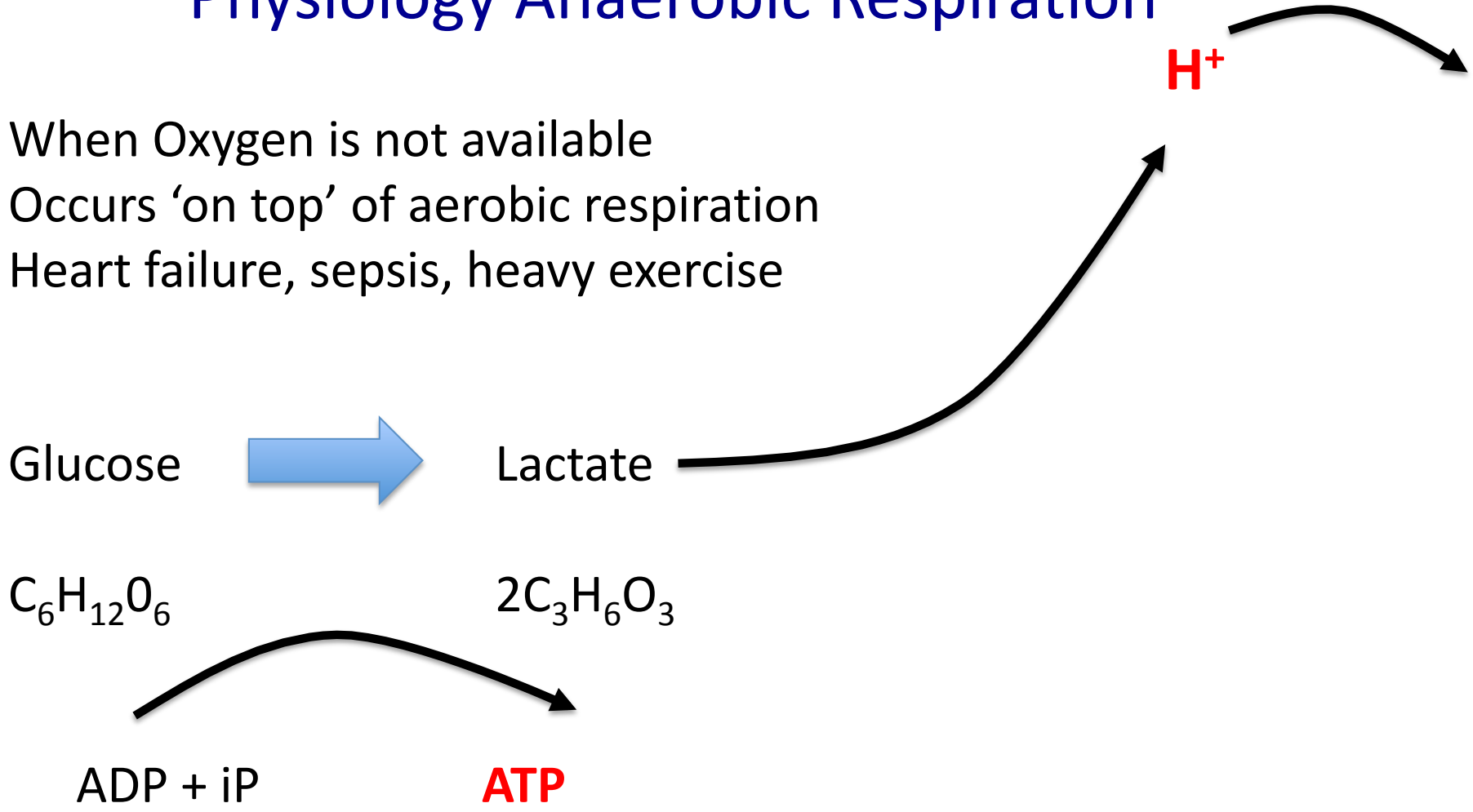
- When we start to detect onset
  of increased Anaerobic respiration


Anaerobic glycolysis
cytosol
Glucose
Glycogen
ATP
ADP
Glucose-1-phosphate
Glucose-6-phosphate
2 ATP
(from glucose)
3 ATP
(from glycogen)
Lactic acid
Pyruvic acid
Lactic acid
Aerobic glycolysis
mitochondrion
Acetyl-CoA
36 ATP
Krebs
cycle

Melzer 2016

Physiology Anaerobic Respiration

When Oxygen is not available
Occurs 'on top' of aerobic respiration
Heart failure, sepsis, heavy exercise



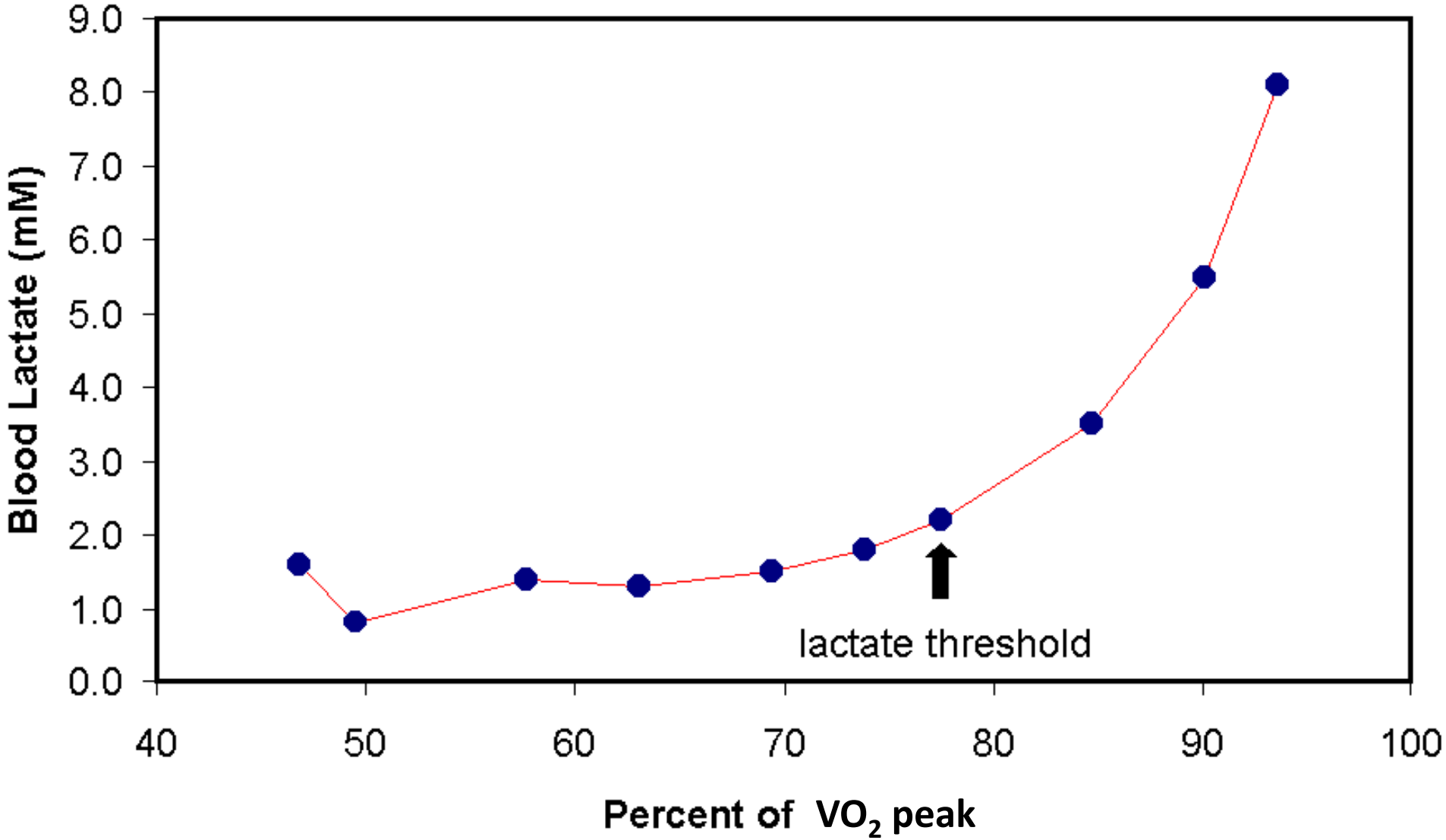
The ‘Anaerobic threshold’ AT

What happens?

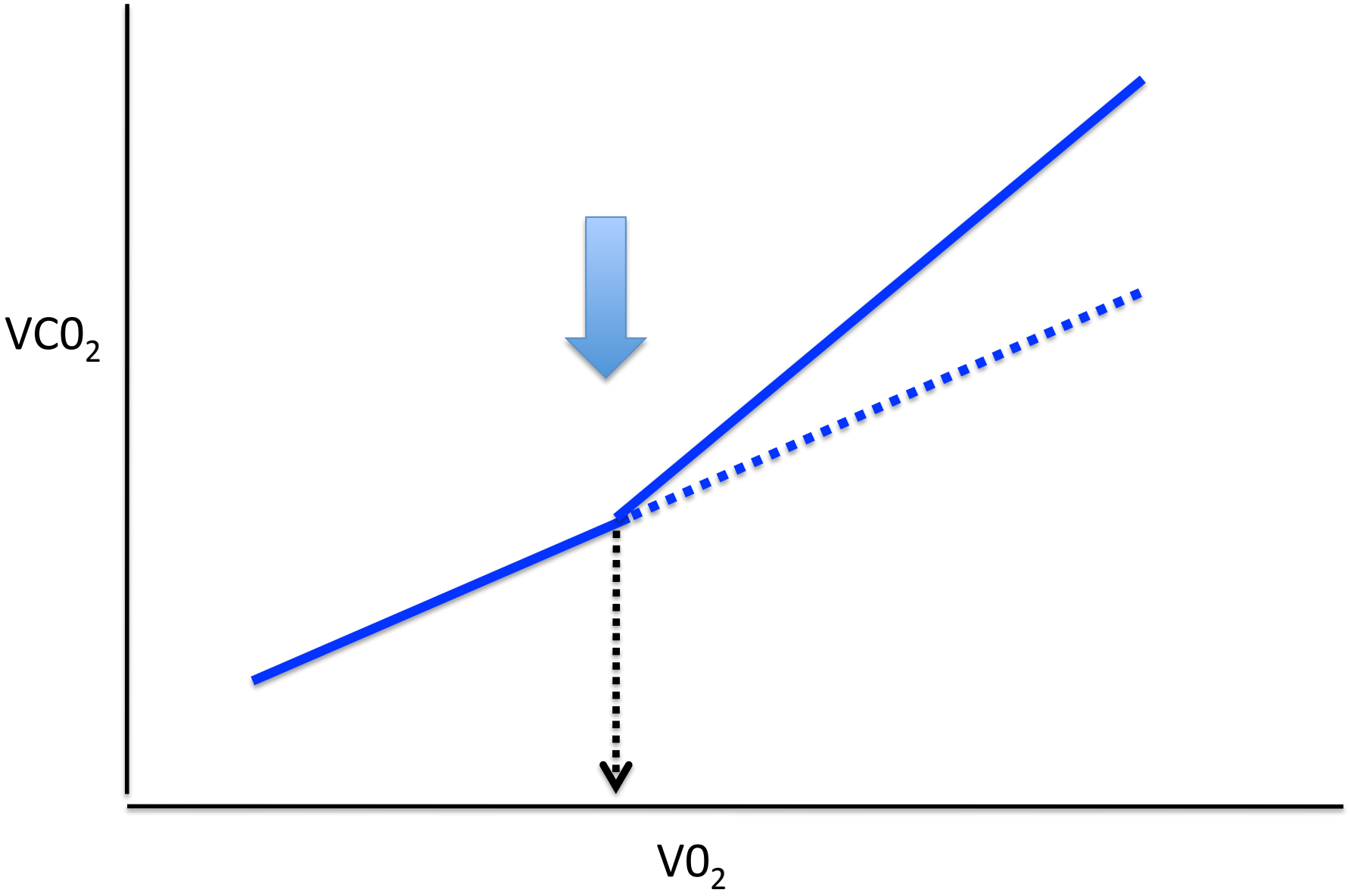
Buffering causes rise in CO_2 measured

At the AT VCO_2 starts to rise at higher rate than the VO_2

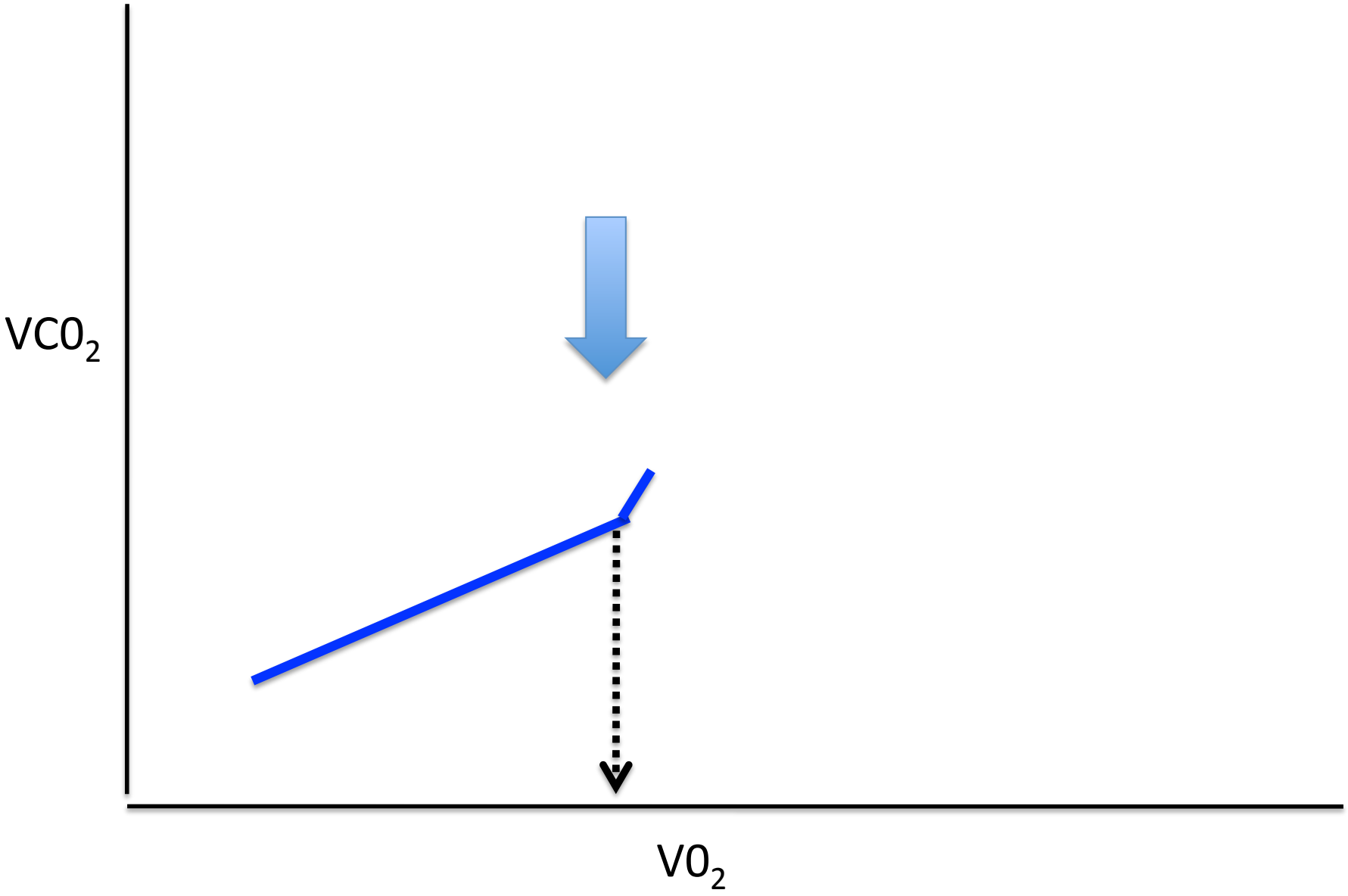
Lactate Level vs Running Intensity



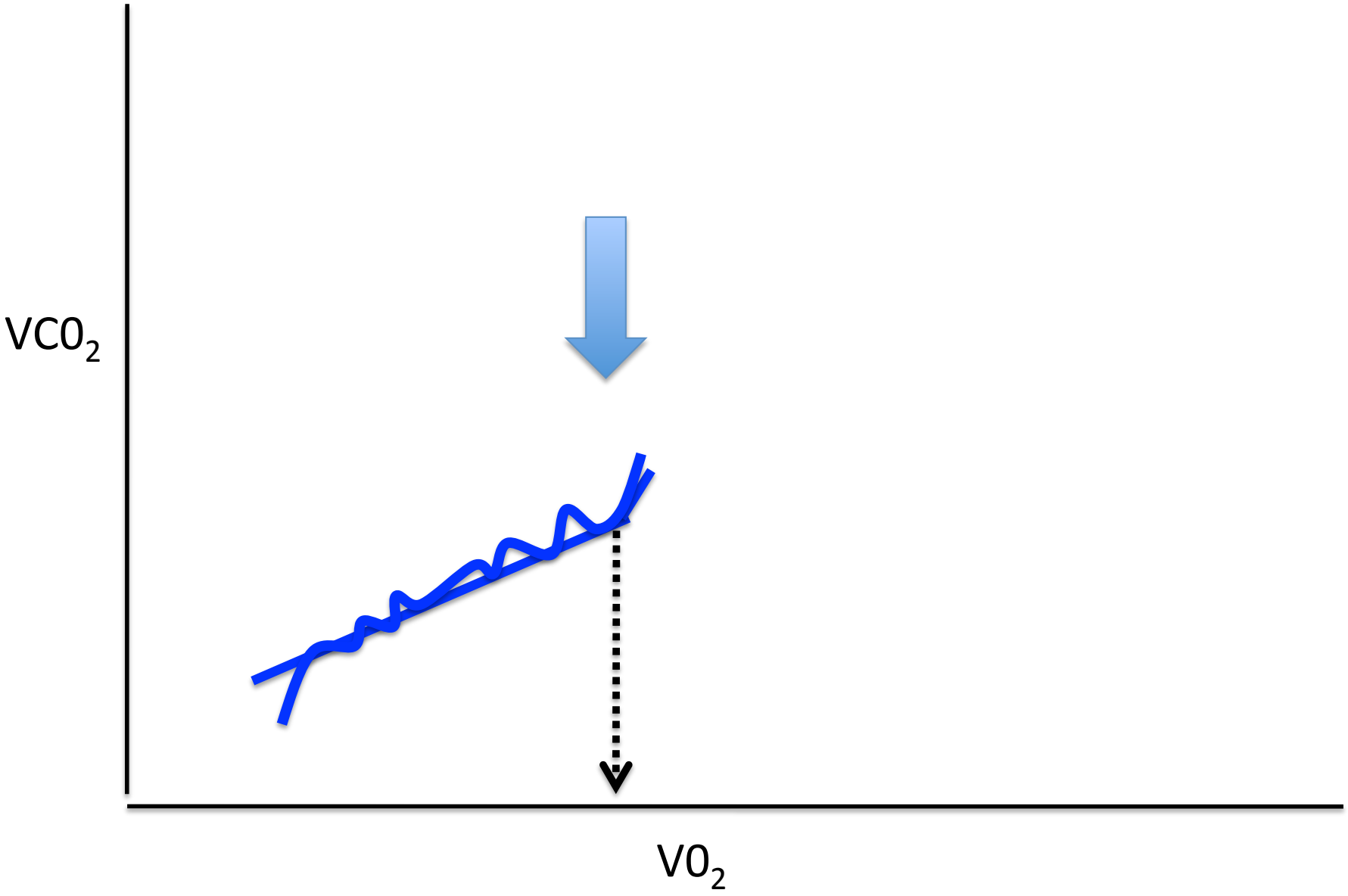
The ‘Anaerobic threshold’ AT V slope

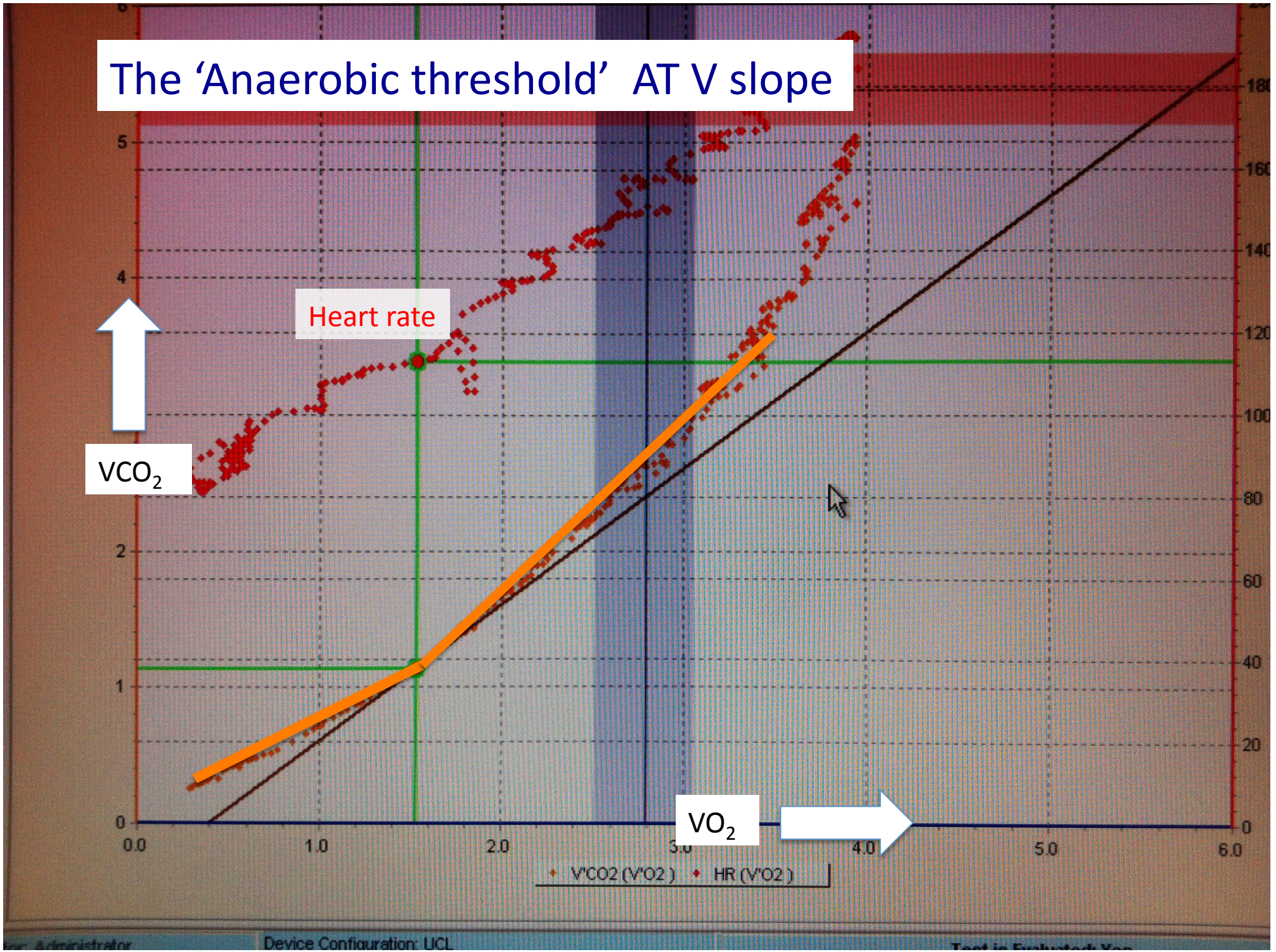


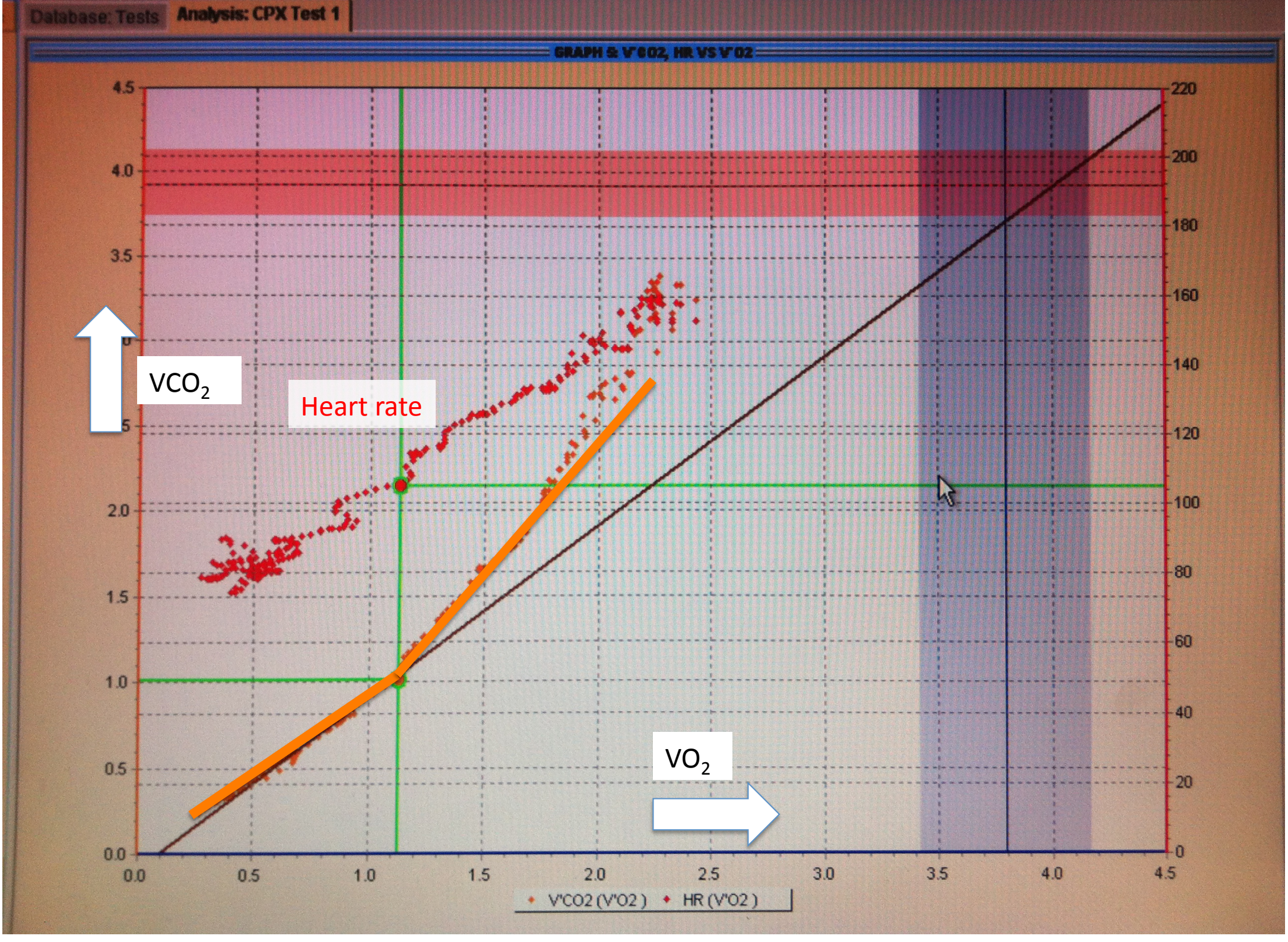
The ‘Anaerobic threshold’ AT V slope



The ‘Anaerobic threshold’ AT V slope




The ‘Anaerobic threshold’ AT V slope
Heart rate
VCO2
VO2
0.0
1.0
2.0
3.0
4.0
5.0
6.0
V'CO2 (V'O2)
HR (V'O2)
Device Configuration: UCL


Database: Tests
Analysis: CPX Test 1
GRAPH 5: V'CO2, HR VS V'O2
VCO2
Heart rate
VO2
V'CO2 (V'O2)
HR (V'O2)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
20
40
60
80
100
120
140
160
180
200
220

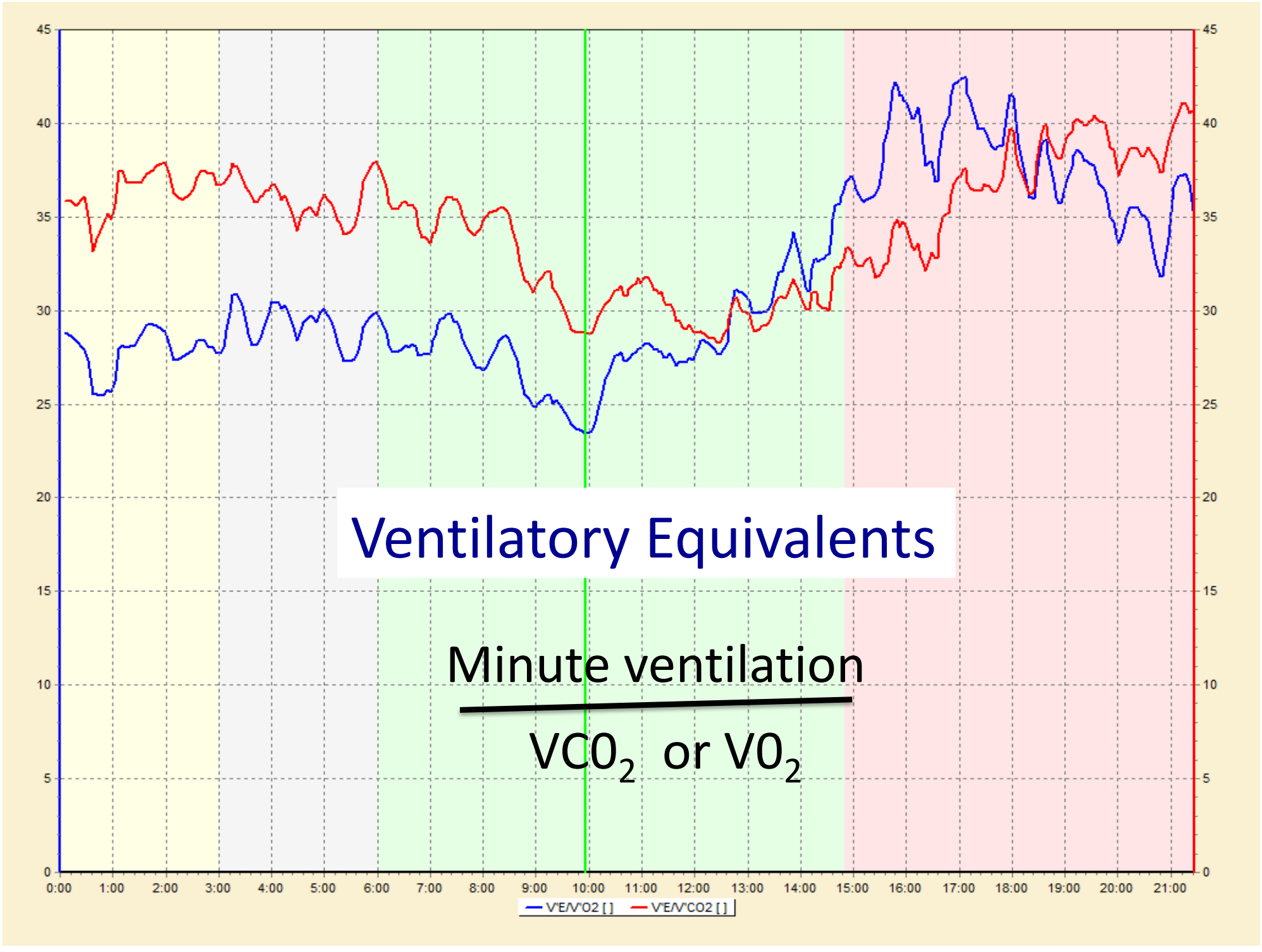
VO_2 @ Anaerobic Threshold

‘Ventilatory Equivalents’

$$\frac{\text{Minute ventilation in l/min}}{VC0_2 \text{ or } V0_2 \text{ in l/min}}$$

‘amount in Litres you have to breathe to get rid of 1L $C0_2$ each minute’

Someone with good lungs vs rubbish lung Function
(eg COPD / heart failure)
Useful measure of efficiency of ventilation
Measure of deadspace
Characteristic pattern in exercise


Ventilatory Equivalents
Minute ventilation
VC0$_2$ or V0$_2$
V'E/V'O2 [ ]
V'E/V'CO2 [ ]

Ventilatory Equivalents

CPET: How to do a test

- Pretest questions:
  Hb, FEV_1 /FVC – 'breathe as much as you can for as long'

- Sit on Exercise ergometer 'bike'; attach leads; start recording

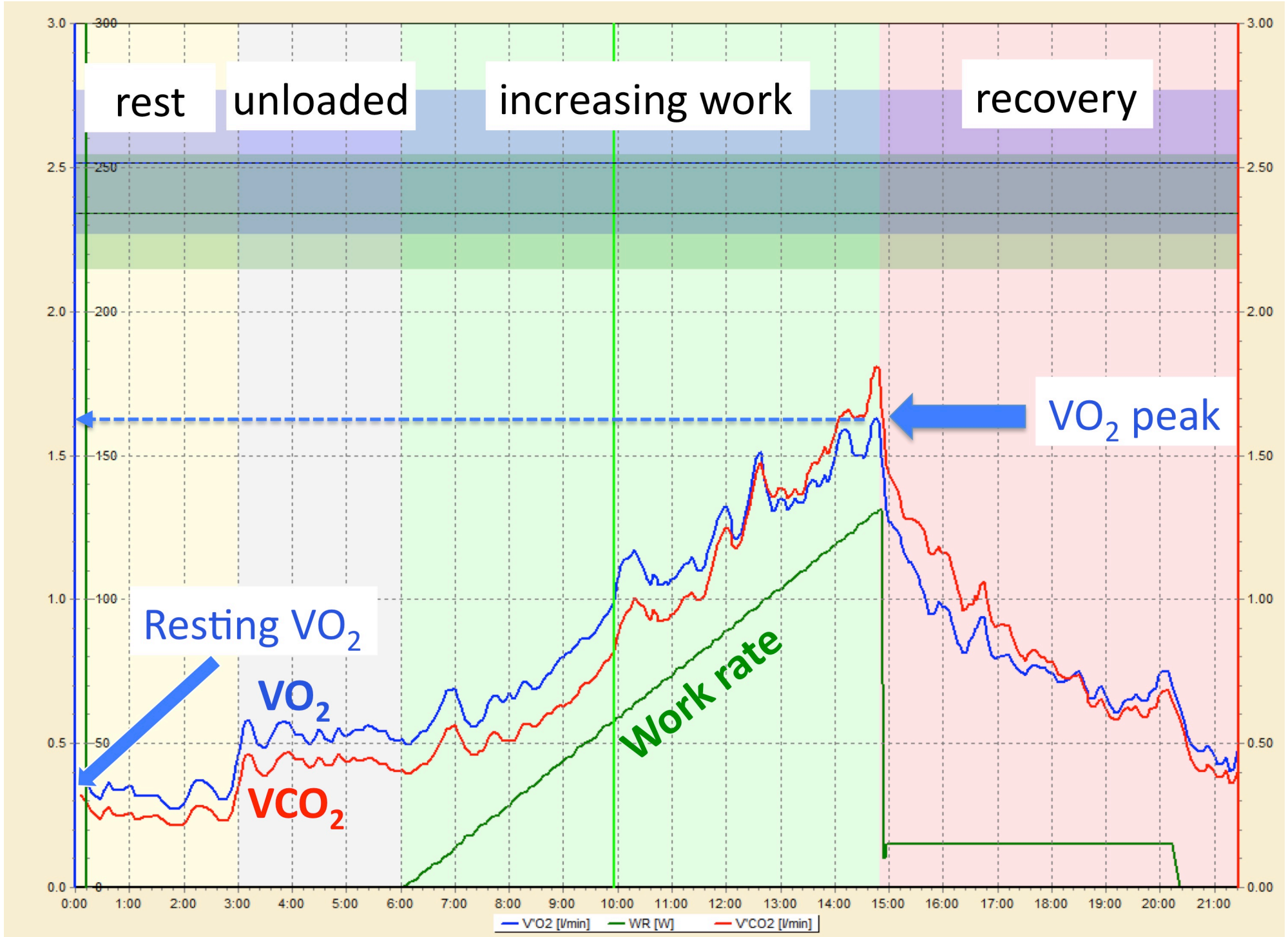
- Rest 3 minutes

- 'Unloaded' exercise 3 minutes- 'pedalling'

- Slowly increase resistance- according to how fit the patient is

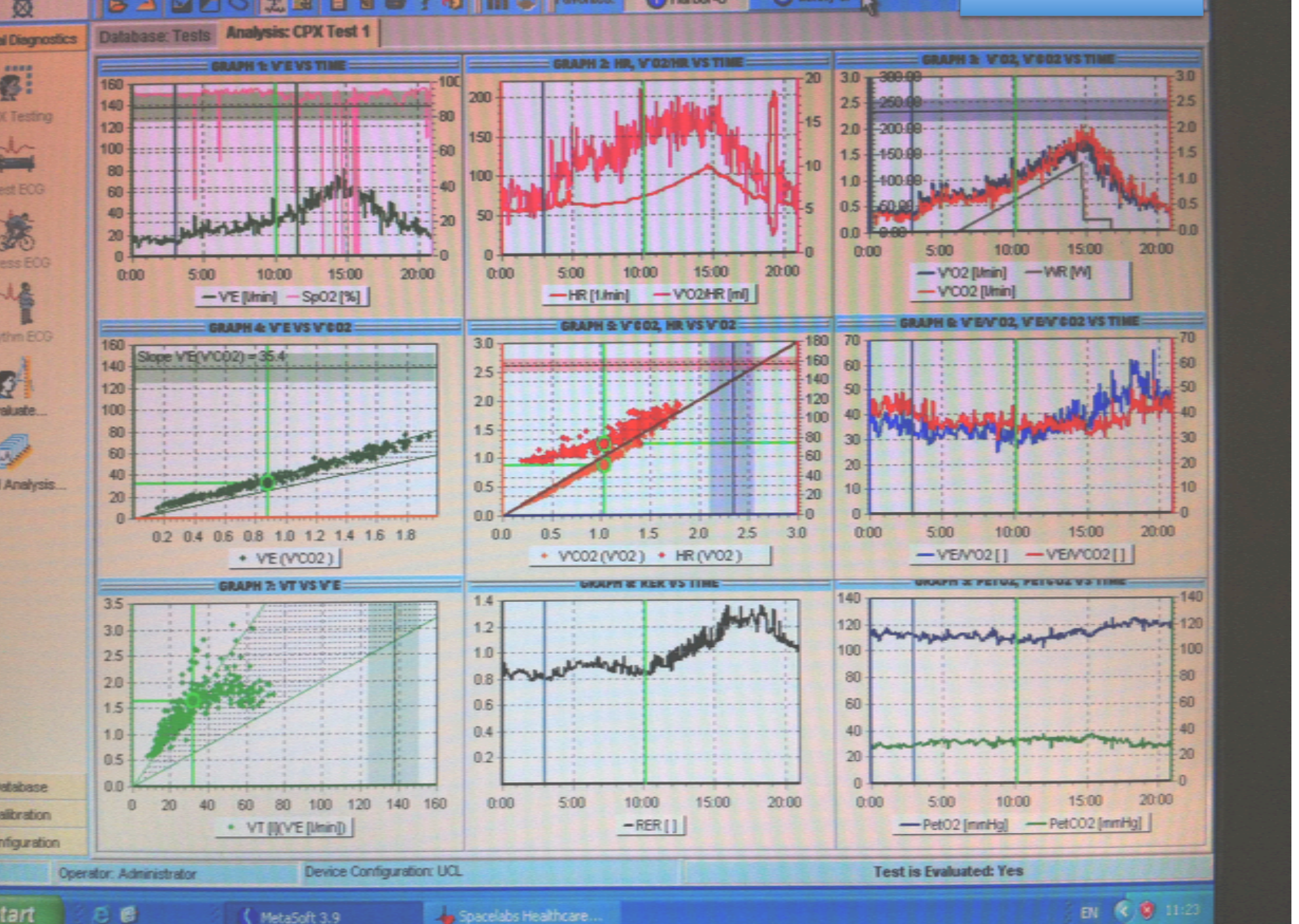
- Stop when patient can go no more & record reason

- Wind- down

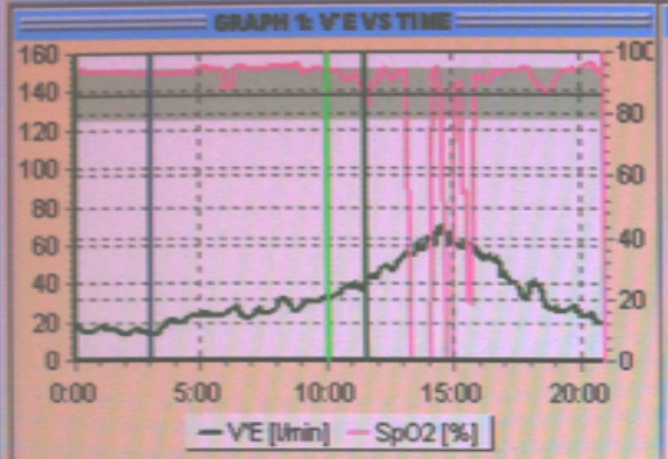

rest
unloaded
increasing work
recovery
VO_2 peak
Resting VO_2
VO_2
VCO_2
Work rate
V'O2 [l/min]
WR [W]
V'CO2 [l/min]

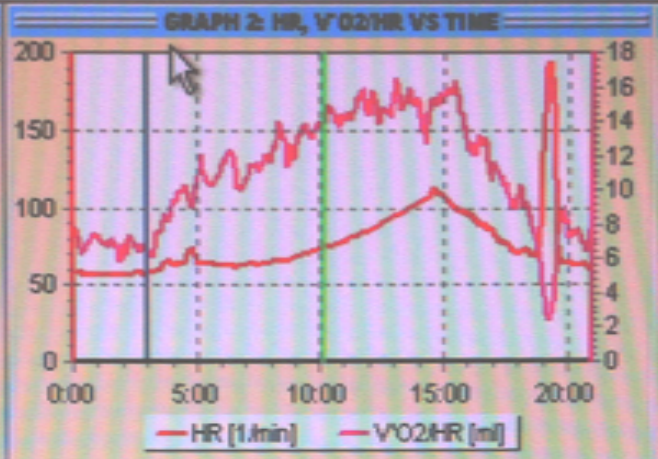
CPET: Before analysing a test

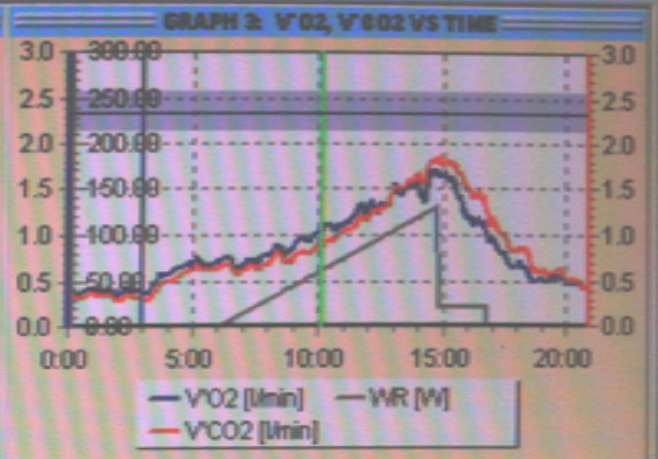
- Is the data reliable?
- Is it smoothed/averaged ok ?
- Why was the person tested-what indication?
- Was the test a maximal one?
- Were there any significant clinical events?

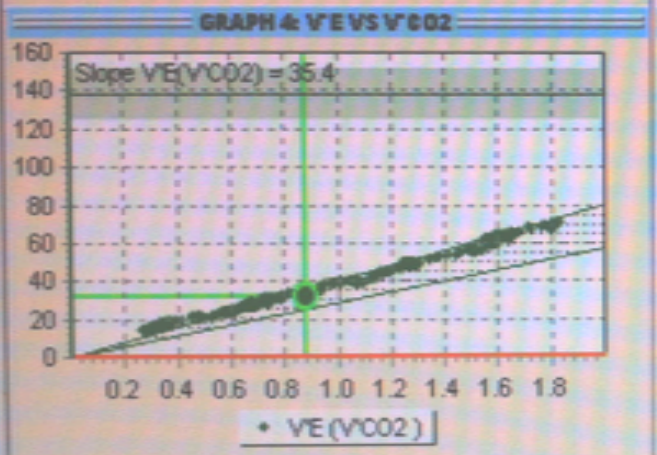

Database: Tests
Analysis: CPX Test 1
GRAPH 1: V'E VS TIME
V'E [l/min]
SpO2 [%]
GRAPH 2: HR, V'O2/HR VS TIME
HR [1/min]
V'O2/HR [ml]
GRAPH 3: V'O2, V'CO2 VS TIME
V'O2 [l/min]
WR [W]
V'CO2 [l/min]
GRAPH 4: V'E VS V'CO2
Slope VE(V'CO2) = 35.4
VE (V'CO2)
GRAPH 5: V'CO2, HR VS V'O2
V'CO2 (V'O2)
HR (V'O2)
GRAPH 6: V'E/V'O2, V'E/V'CO2 VS TIME
VE/VO2 [ ]
VE/VCO2 [ ]
GRAPH 7: VT VS V'E
VT [l](V'E [l/min])
GRAPH 8: RER VS TIME
RER [ ]
PetO2 [mmHg]
PetCO2 [mmHg]
Operator: Administrator
Device Configuration: UCL
Test is Evaluated: Yes

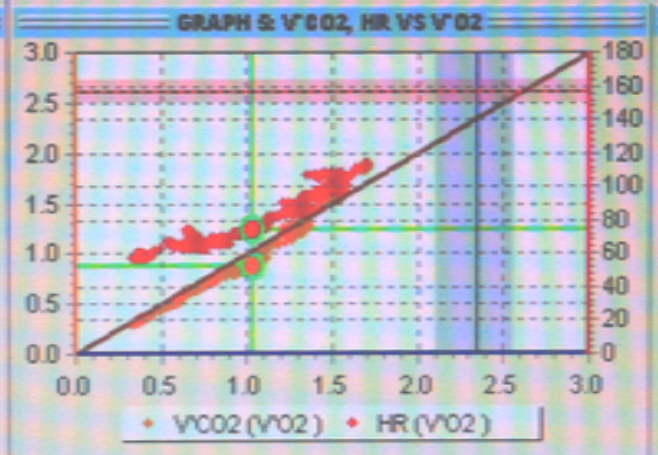
Database: Tests | Analysis: CPX Test 1

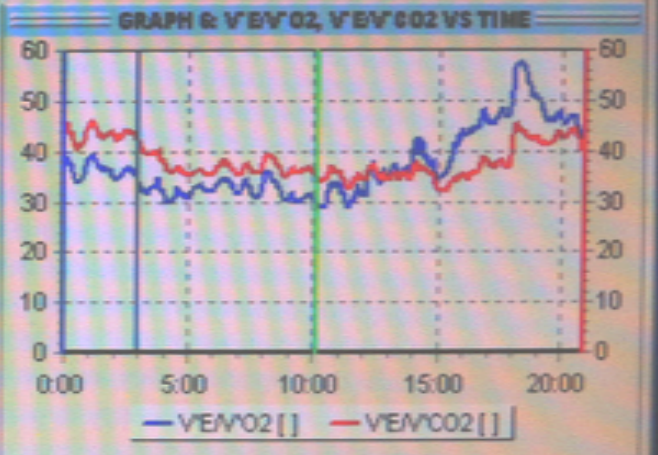


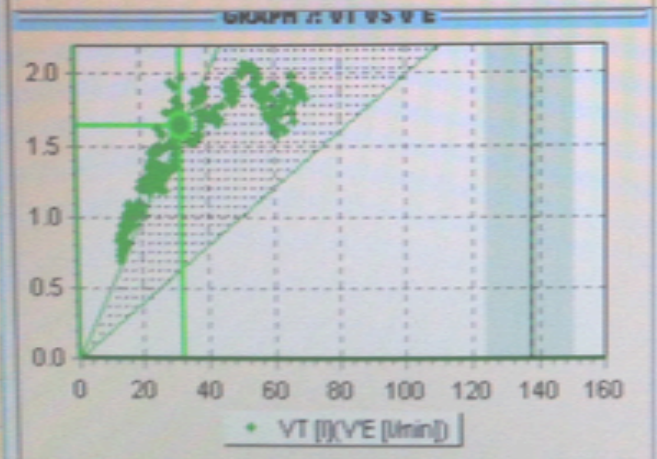


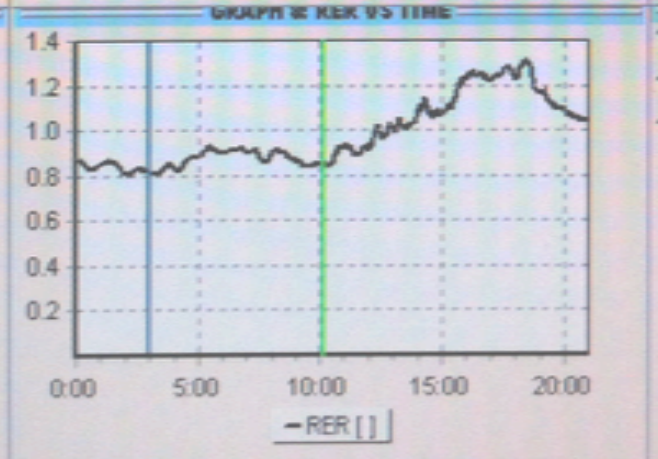


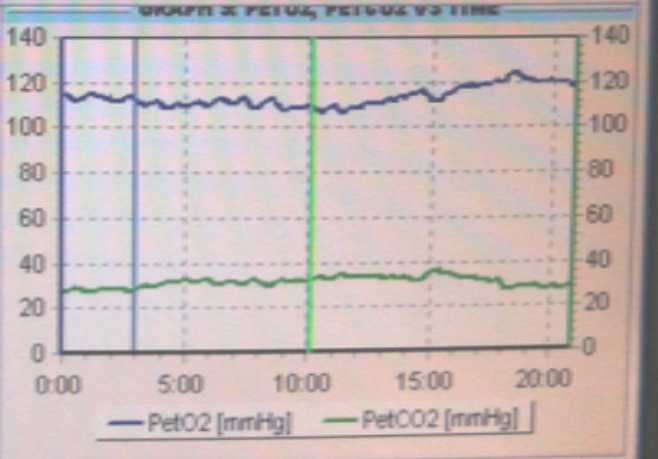




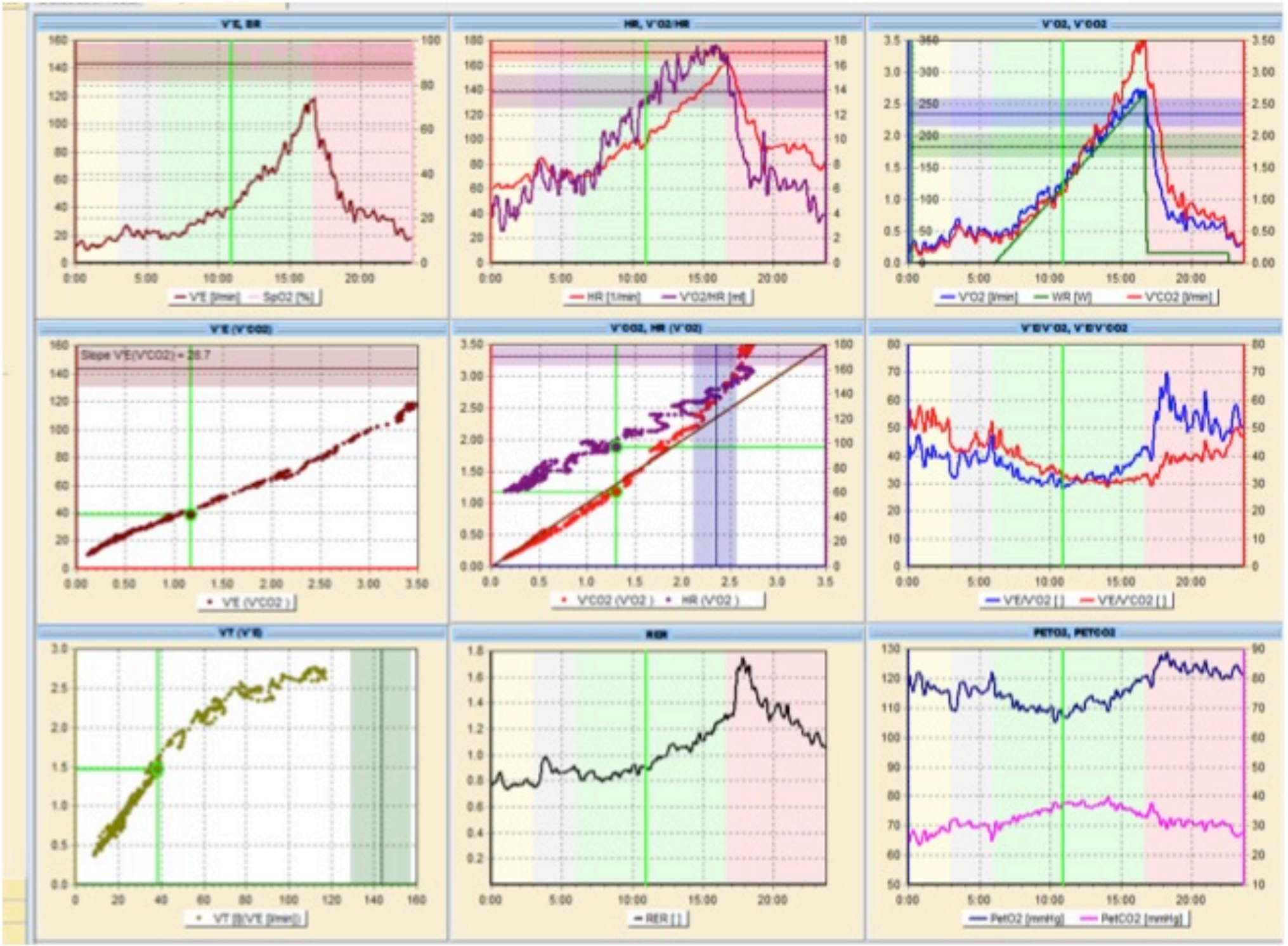








Operator: Administrator | Device Configuration: UCL | Test is Evaluated: Yes


V'E, SR
V'E [l/min]
SpO2 [%]
HR, V'O2/HR
HR [1/min]
V'O2/HR [ml]
V'O2, V'CO2
V'O2 [l/min]
WR [W]
V'CO2 [l/min]
V'E (V'CO2)
Slope V'E(V'CO2) = 28.7
V'E (V'CO2)
V'CO2, HR (V'O2)
V'CO2 (V'O2)
HR (V'O2)
V'EV'O2, V'EV'CO2
VE/VO2 [ ]
VE/VCO2 [ ]
VT (V'E)
VT [l] (V'E [l/min])
RER
RER [ ]
PETO2, PETCO2
PetO2 [mmHg]
PetCO2 [mmHg]

How I analyse: Summary

1 Clinical information Hx, Ex, Ix

2 Pretest information at top of report

3 Why they stopped exercising?

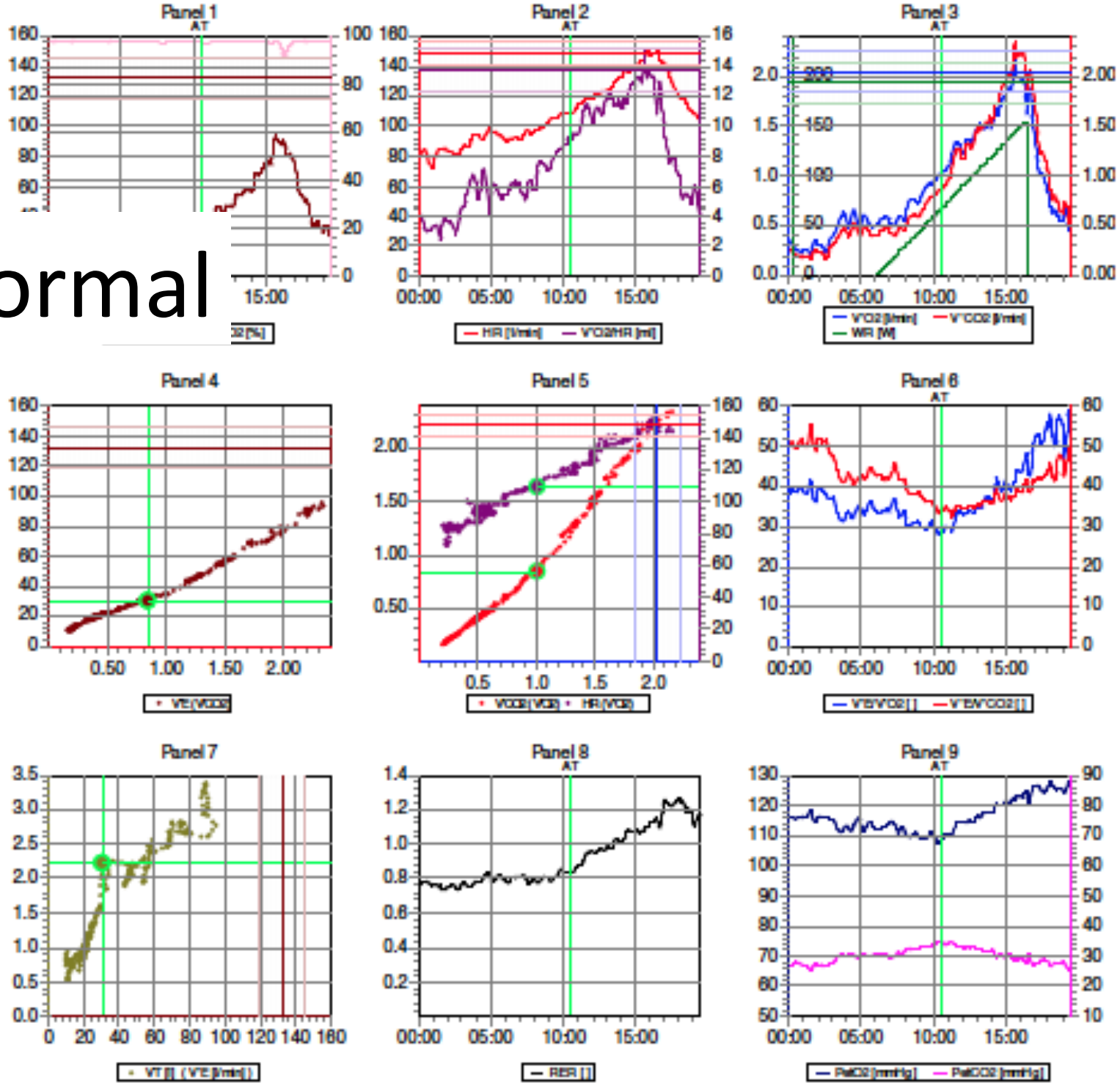
4 Look at 9 panels in an order: like a 12 lead ECG

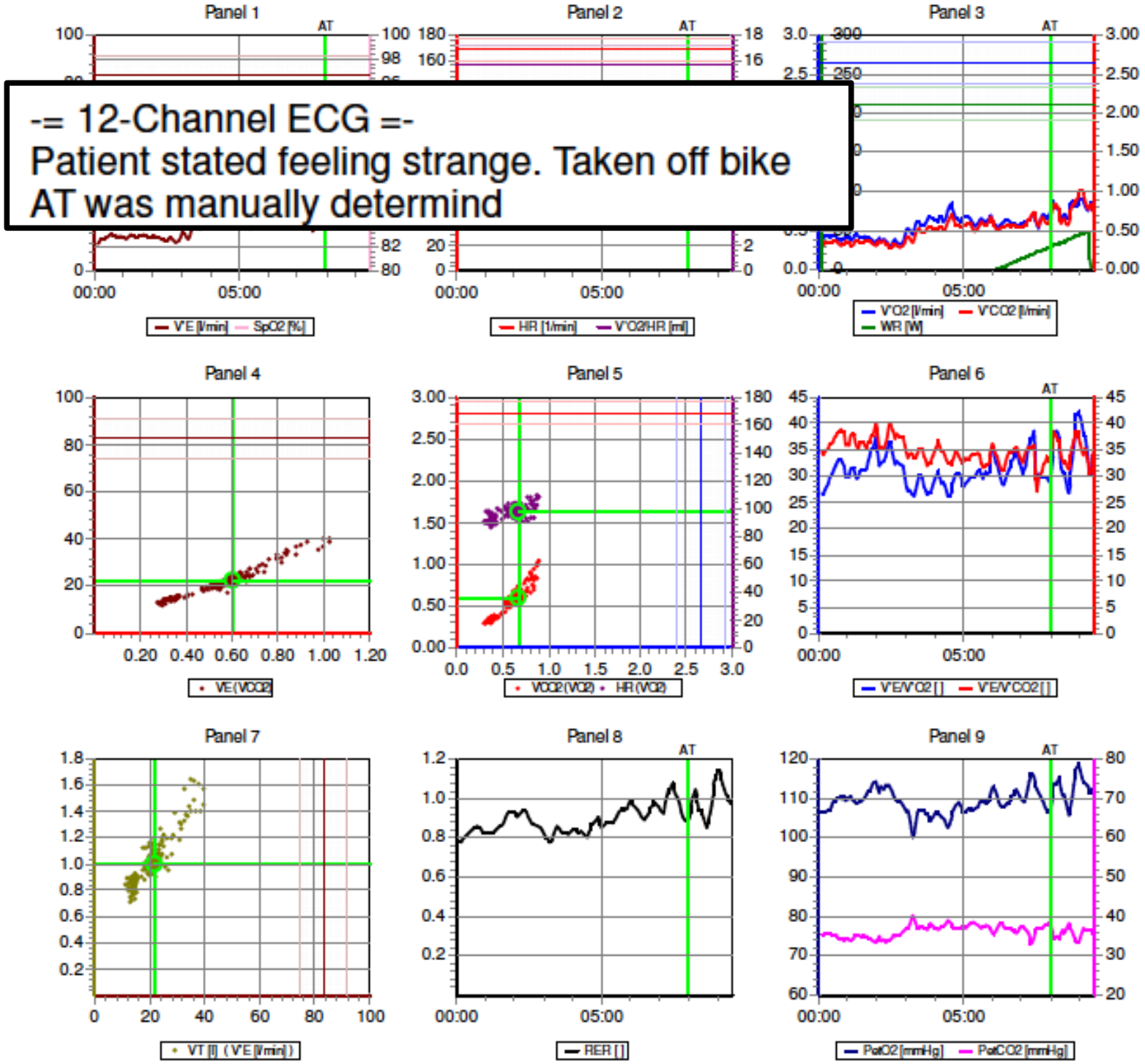
5 Look at the ECG

6 Think

7 Write report, contact relevant people/action

Normal


Panel 1
AT
Panel 2
AT
HR [1/min]
Panel 3
AT
Panel 4
Panel 5
Panel 6
AT
Panel 7
Panel 8
AT
Panel 9
AT



-= 12-Channel ECG =-
Patient stated feeling strange. Taken off bike
AT was manually determind

More Proof That Any Exercise Is Better Than No Exercise

Think that you need to hit the gym or the pavement every single day to be healthy? New research says it only takes a couple workouts to reap the rewards.

By **Charlotte Hilton Andersen**

Pin
FB
More

JAMA Network Open

Editorial

Physical Activity, Fitness, and Cardiovascular Health
Insights From Publications in *JAMA Network Open*

Steven M. Bradley, MD, MPH; Erin D. Michos, MD, MHS; Michael D. Miedema, MD, MPH

Victory! Victory! Rejoice, we conquer!

The last words of Pheidippides before his death, immediately after running the approximate distance of a marathon in 490 BC[1]

Some would believe the story of poor Pheidippides is a cautionary tale about the hazards of exercise. His battery was drained after running 25 miles to convey the outcome of the Battle of Marathon—his finite supply of energy was used up, and he died as a result. What's forgotten is that Pheidippides ran 300 miles in the days preceding his final marathon dash. Fear not the fate of Pheidippides! Yes, a sudden increase in vigorous exercise results in a small and transient increase in cardiovascular risk.[2] However, most individuals need to worry about exercising too little rather than too much. A mountain of scientific evidence has established that physical activity and fitness are both important for optimal cardiovascular health.[3,4]

Despite this well-established evidence, opportunities remain to refine our understanding of the association of physical activity and fitness with cardiovascular health. Just how important is fitness, and just how fit is fit? How much activity is needed to see cardiovascular health benefits? How does fitness contribute to cardiovascular health? Is aerobic fitness or muscular strength more important for cardiovascular health? And how should we measure fitness and guide improvements in cardiovascular health? Six articles in *JAMA Network Open* have advanced our understanding and offered new insights on these questions (**Box**).[5-10]

+ Related article

Author affiliations and article information are listed at the end of this article.

Kodama 2009

- 33 Studies Meta-analysis
- all-cause mortality
- n=102 980 participants and 6910 cases

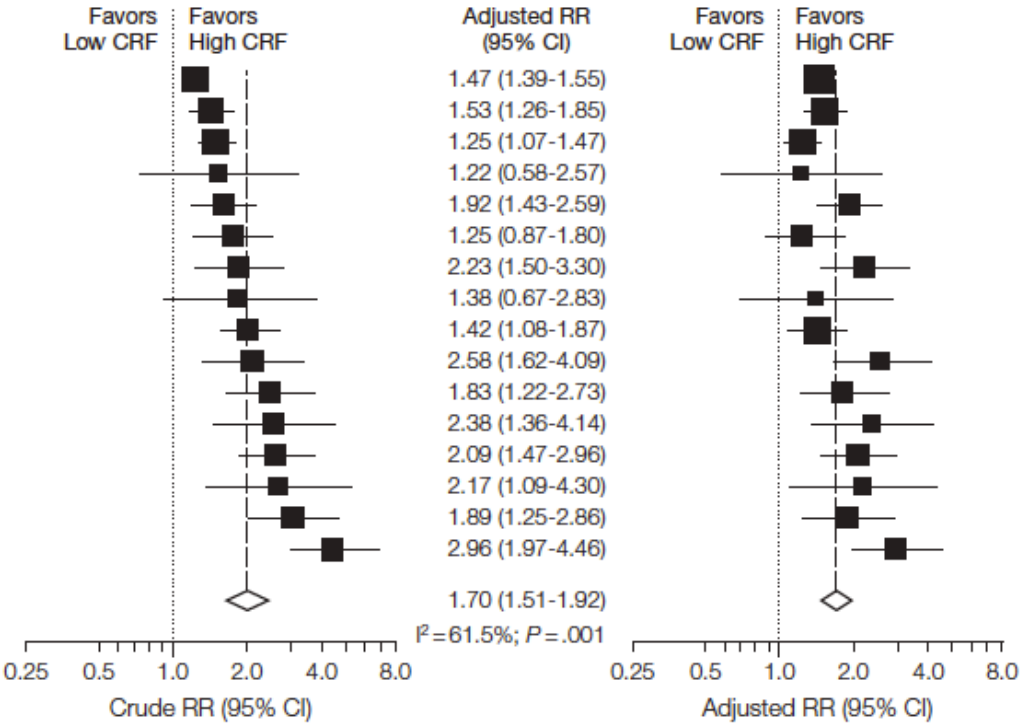
- Classified into low, medium or high fitness

Kodama 2009

Figure 3. Meta-analysis of All-Cause Mortality and CHD/CVD for Individuals With Low vs High CRF

All-Cause Mortality

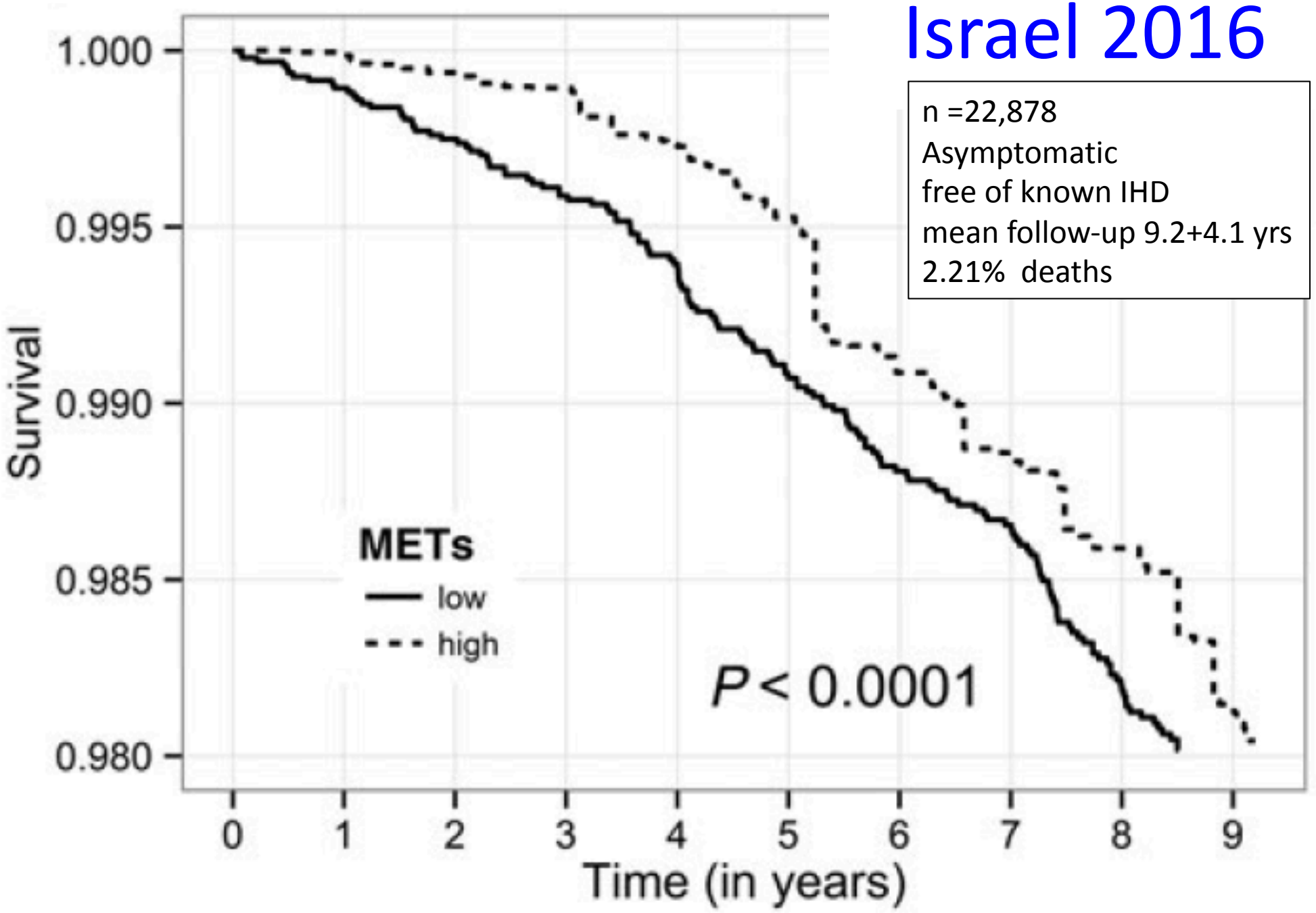
Source	No. of Individuals: Low CRF	No. of Individuals: High CRF	No. of Deaths or Events: Low CRF	No. of Deaths or Events: High CRF	Crude RR (95% CI)	Adjusted RR (95% CI)
Slattery and Jacobs,[5] 1988	NA	NA	NA	NA	1.23 (1.17-1.30)	1.47 (1.39-1.55)
Hein et al,[42] 1992	976	994	78	47	1.43 (1.18-1.73)	1.53 (1.26-1.85)
Aijaz et al,[29] 2008	NA	NA	NA	NA	1.50 (1.28-1.76)	1.25 (1.07-1.47)
Villeneuve et al,[53] 1998	321	3935	8	80	1.52 (0.72-3.19)	1.22 (0.58-2.57)
Stevens et al,[21] 2002 [men]	NA	NA	260	64	1.59 (1.18-2.14)	1.92 (1.43-2.59)
Farrell et al,[38] 2002	1657	4521	75	57	1.75 (1.22-2.53)	1.25 (0.87-1.80)
Stevens et al,[21] 2002 [women]	NA	NA	208	33	1.84 (1.24-2.72)	2.23 (1.50-3.30)
Sandvik et al,[50] 1993	490	487	106	24	1.85 (0.90-3.80)	1.38 (0.67-2.83)
Kampert et al,[44] 1996	3436	7343	197	81	2.04 (1.55-2.68)	1.42 (1.08-1.87)
Stevens et al,[22] 2004	NA	NA	77	24	2.13 (1.34-3.38)	2.58 (1.62-4.09)
Laukkanen et al,[9] 2008	410	410	124	39	2.48 (1.66-3.71)	1.83 (1.22-2.73)
Sawada and Muto,[51] 1999	1793	1889	96	17	2.56 (1.47-4.47)	2.38 (1.36-4.14)
Erikksen et al,[36] 1998	357	357	97	37	2.62 (1.85-3.72)	2.09 (1.47-2.96)
Arraiz et al,[32] 1992	833	801	36	12	2.70 (1.36-5.35)	2.17 (1.09-4.30)
Gulati et al,[16] 2003	NA	NA	NA	NA	3.10 (2.05-4.69)	1.89 (1.25-2.86)
Myers et al,[47] 2002	NA	NA	NA	NA	4.52 (3.00-6.80)	2.96 (1.97-4.46)
Overall					2.00 (1.66-2.42)	1.70 (1.51-1.92)
					$I^2 = 86.7\%$; $P < .001$	$I^2 = 61.5\%$; $P = .001$



CHD/CVD

Israel 2016

n =22,878
Asymptomatic
free of known IHD
mean follow-up 9.2+4.1 yrs
2.21% deaths



Older 1993; Mortality

n=187

Table 1—*Mortality Data: AT Above and Below 11 ml/min/kg**

AT, ml/min/kg	No.	CVS Deaths	Percentage Mortality
<11	55	10	18
≥11	132	1	0.8
Totals	187	11	(p<0.001)

*AT = anaerobic threshold; CVS = cardiovascular.

min/kg, there were 19 who demonstrated preoperative ischemia as defined above (Table 2). This group had a CVS mortality rate of 42 percent. In those patients in whom the AT was greater than 11 ml/min/kg, there were 25 patients with preoperative ischemia. This group had a mortality of 4 percent. There is a significant difference between these two groups (p<0.01).

Discussion

To our knowledge, this is the first time that CPX has been used prospectively to evaluate the cardiopulmonary function of surgical patients. In a previous study of preoperative hemodynamic status of 100

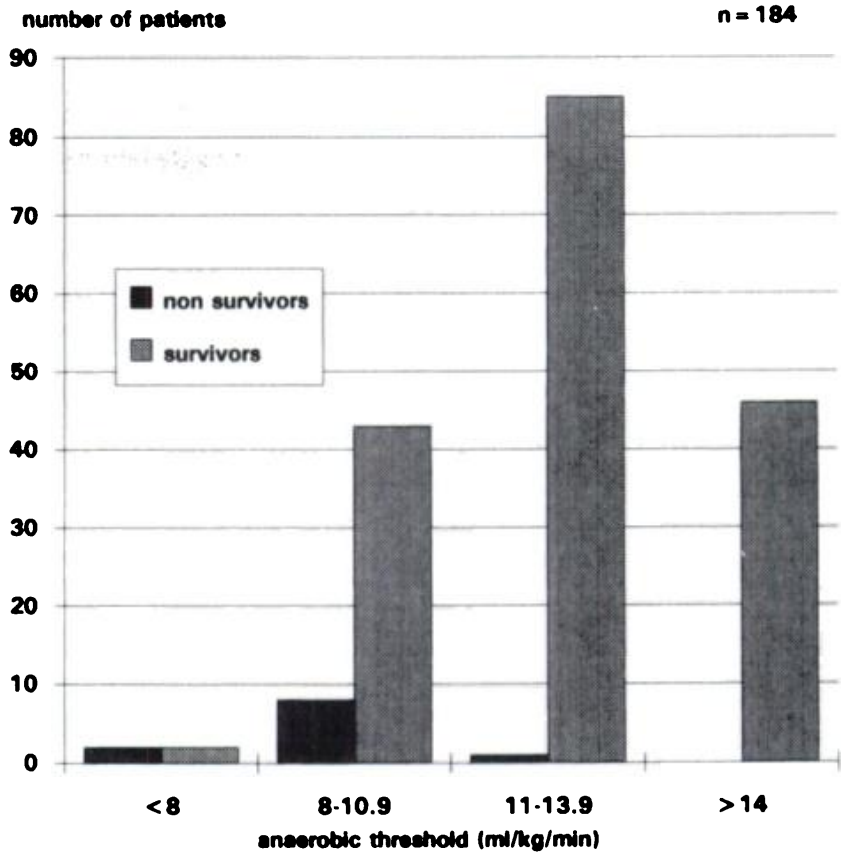


Figure 3. Comparison of cardiovascular mortality with anaerobic threshold.

may result from myocardial ischemia, but in the

Older 1999; Mortality

Lower anaerobic threshold: higher mortality
Inefficient lungs: higher mortality

	Mortality
AT less 11 ml/min /kg	4.6%
AT more 11 ml/min /kg but other badness	1.7%
AT more 14 ml/min /kg	0%

n=548; Older 1999

$V0_2$ @AT and Complications

Complication on day 7 POMS	**$V0_2$ @AT < 10.1 n= 51**	**$V0_2$ @AT AT > 10.1 n=65**	**p=**
Pulmonary	57%	15%	<0.0001
Renal	40%	11%	0.0004
GI	33%	11%	0.005
Infective	27%	11%	0.003
Cardiovascular	25%	3%	0.0005
Neurological	10%	5%	0.29
Hematology	8%	0	0.04
Pain	8%	0	0.04
Wound	4%	0	0.2

Snowden 2010

Moran 2016

Table 4: Preoperative Cardiopulmonary Exercise Testing and Length of Stay

Cardiopulmonary Exercise Testing and Length of Stay				
Author	**Sample Size**	**Hospital LOS**	**ICU/CCU Admission**	**ICU/CCU LOS**
Hepatic Transplant and Resection				
Bernal and colleagues[14]	223	AT <9.2 ml/kg/min,	–	Vo_2 Peak <13.4 ml/kg/min
Dunne and colleagues[18]				
Junejo and colleagues[12]				.9 ml/kg/min
Prentis and colleagues[13]				.1 ml/kg/min
Abdominal Aortic Aneurysm				
Prentis and colleagues[23]				.0 ml/kg/min (Open Repair)
Colorectal				
Lai and colleagues[24]				
West and colleagues[26]	136	AT, Vo_2 Peak, V_E/Vco_2	–	–
Pancreatic				
Ausania and colleagues[28]	124	AT ≤10.1 ml/kg/min	–	–
Chandrabalan and colleagues[29]	100	AT (<10 ml/kg/min	–	–
Renal Transplant				
Ting and colleagues[33]	70	–	AT	–
Upper Gastrointestinal				
Forshaw and colleagues[34]	78	AT <11 ml/kg/min – Not Significant	–	–
Bariatric				
McCullough and colleagues[37]	109	Vo_2 Peak*	–	–
Hennis and colleagues[38]	106	AT <11.4 ml/kg/min	–	–
Intra-Abdominal				
Snowden and colleagues[39]	389	AT <10 ml/kg/min	–	AT <10 ml/kg/min
Tolchard and colleagues[45]	105	AT, V_E/Vco_2	Vo_2 Peak*	–
Wilson and colleagues[40]	847	AT <11 ml/kg/min	–	–

"Cardiopulmonary exercise testing is a useful preoperative risk-stratification tool that can predict postoperative outcome. Further research is needed….."

Hennis 2011

Author, year (reference)	Type of surgery	Population (selection criteria)	Prospective vs retrospective	Design	Blinded from CPET results*
Older *et al* (1993)[5]	Major intra-abdominal	187 patients (age >60 years)	Not stated	Observational	✗
Older *et al* (1999)[13]	Major intra-abdominal	548 patients (>60 years or <60 years with previous MI or heart failure)	Prospective	Intervention	✗
Snowdon *et al* (2010)[8]	Major intra-abdominal	116 patients (METS <7)	Prospective	Observational	✓
Wilson *et al* (2010)[9]	Major intra-abdominal	843 patients (>55 years, or <55 years with comorbidities)	Retrospective	Observational	✗
Hightower *et al* (2010)[16]	Major intra-abdominal	32 patients	Prospective	Observational	✓
Nagamatsu *et al* (1994)[17]	Upper GI (thoracolaparotomy for oesophageal cancer)	52 patients	Not stated	Observational	✗
Nagamatsu *et al* (2001)[18]	Upper GI (oesophagectomy + lymphadenectomy)	91 patients	Retrospective	Observational	✗
Forshaw *et al* (2008)[19]	Upper GI (oesophagectomy)	78 consecutive patients	Not stated	Observational	✗
McCullough *et al* (2006)[12]	Upper GI (laparoscopic gastric bypass)	109 patients (BMI >35 kg/m^2 with diabetes or >40 kg/m^2 without)	Not stated	Observational	✗
Nugent *et al* (1998)[20]	AAA repair	30 patients	Not stated	Observational	✗
Carlisle and Swart (2007)[14]	AAA repair	130 patients	Not stated	Observational	✗
Epstein *et al* (2004)[21]	Hepatic transplantation	59 patients	Not stated	Observational	✗

Perioperative CPET: our data

Colorectal Hospital Stay

N=419: UCLH and Whittington

and….. adding breathing parameters with AT..

Variable	**Stay days**
AT < 11.0 and $VE/VCO_2 \geq 31.5$	**13** (6-20)
AT ≥ 11.0 and $VE/VCO_2 < 31.5$	**8** (3-13)

Perioperative CPET: our data

Colorectal Mortality

N=419: UCLH and Whittington

Variable	**1 year mortality Odds Ratio (95% CI)**
AT < 11.0	**No association**
$VE/VCO_2 \geq 31.5$	**2.77** (95% CI 1.74-4.41)
Low VO_2 peak	**2.70** (95% CI 1.58-4.54)

Perioperative CPET: so far

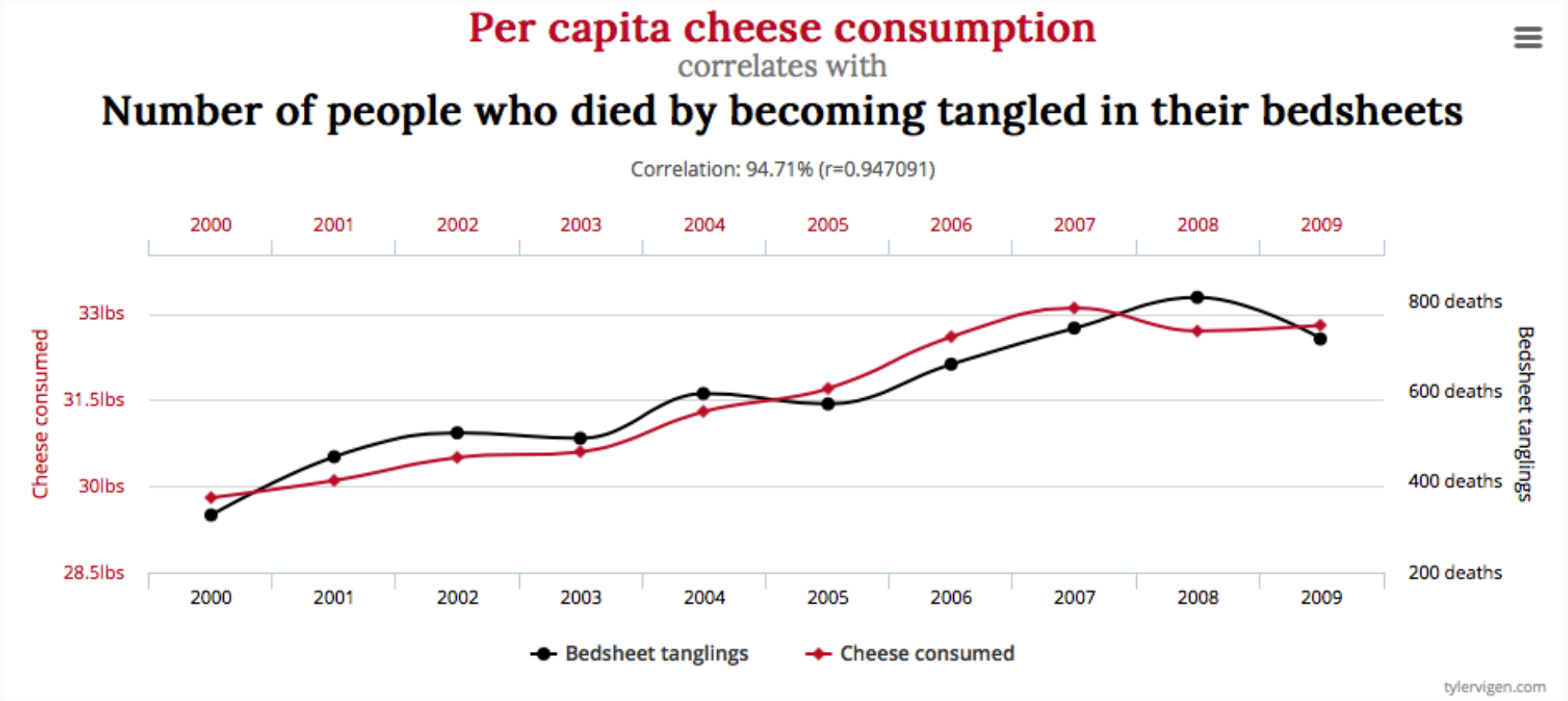
- $V0_2$ @AT >11
- $V0_2$ @Peak >15
- $VE/VC0_2$ @AT <34

} Associations

- ECG
- Specific Pathologies
- Ward vs ICU, consent, less surgery, specific Rx

tylervigen.com
Google Mail Work Home Popular Travel Food Music London Kids house work

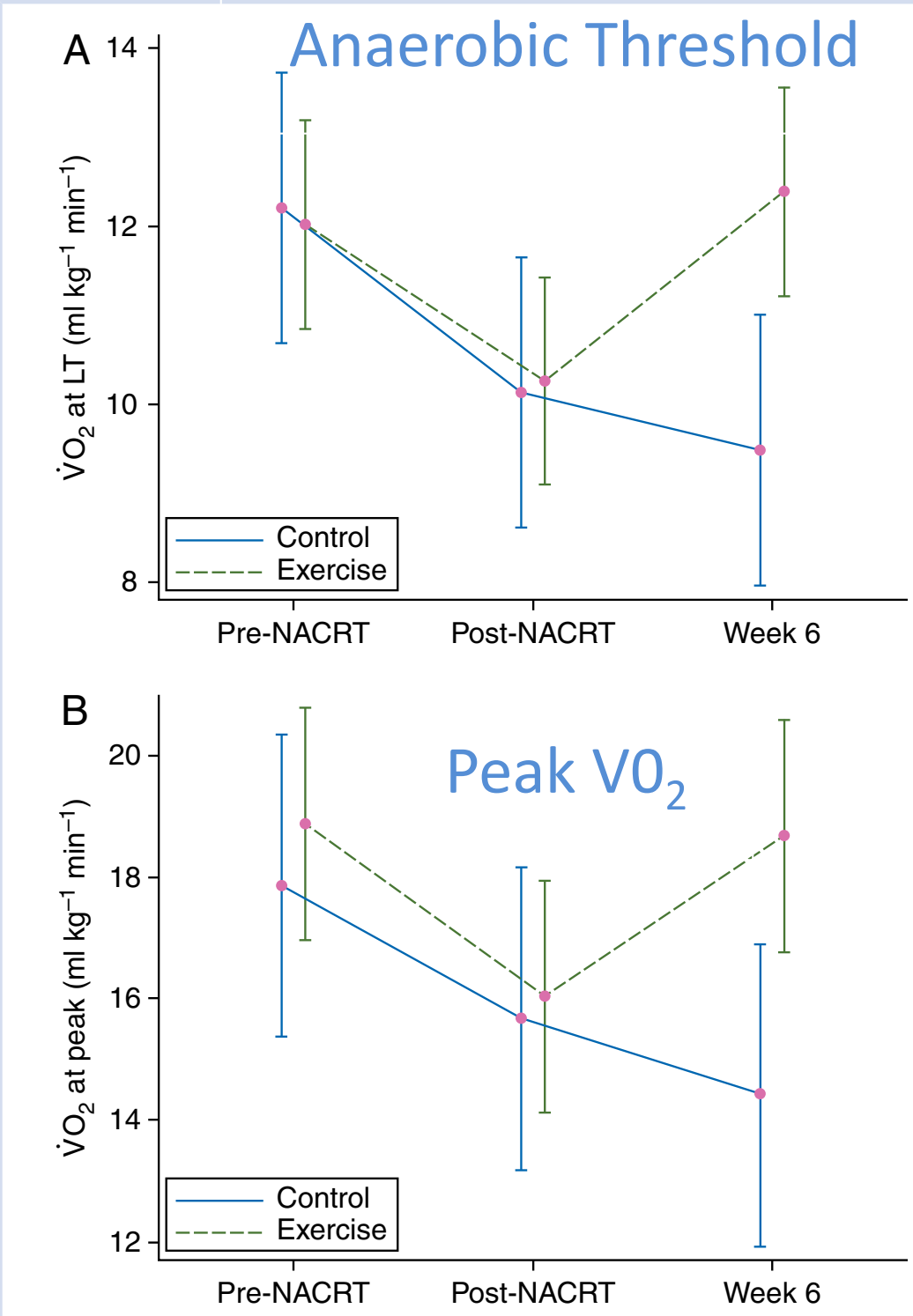
Association/Correlation doesn't equal causation



Data sources: U.S. Department of Agriculture and Centers for Disease Control & Prevention

West 2015

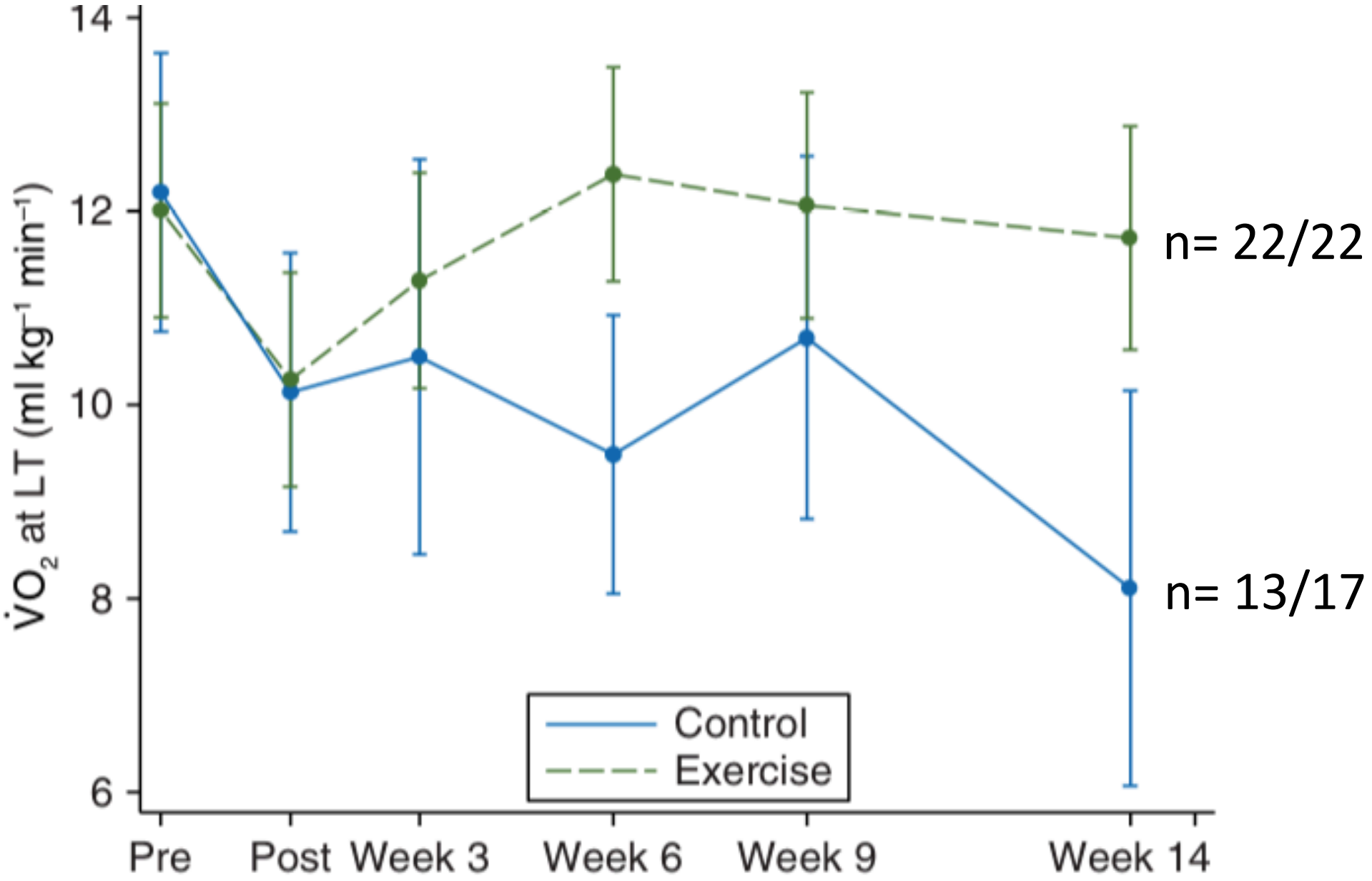
- 39 subjects with rectal cancer
- neoadjuvant chemoradiotherapy
- non-randomized
- 22 out of 22 (exercise) vs 13 out of 17 (control) completed the study
- There were differences between the exercise and control groups at baseline
  - age
  - ASA score physical status
  - World Health Organisation performance status Colorectal POSSUM



fitted means and 95% CI

Exercise n= 22/22

Control n= 13/17


14
12
10
8
6
$\dot{V}O_2$ at LT (ml kg^{-1} min^{-1})
Pre
Post
Week 3
Week 6
Week 9
Week 14
Control
Exercise
n= 22/22
n= 13/17

Summary

- Reasons to do test
- Basics of a test
- What we take away from test
- Test examples
- CPET vs outcomes

- Thanks

$V0_2$ @AT
$V0_2$ @Peak
$VE/VC0_2$ @AT

Other info