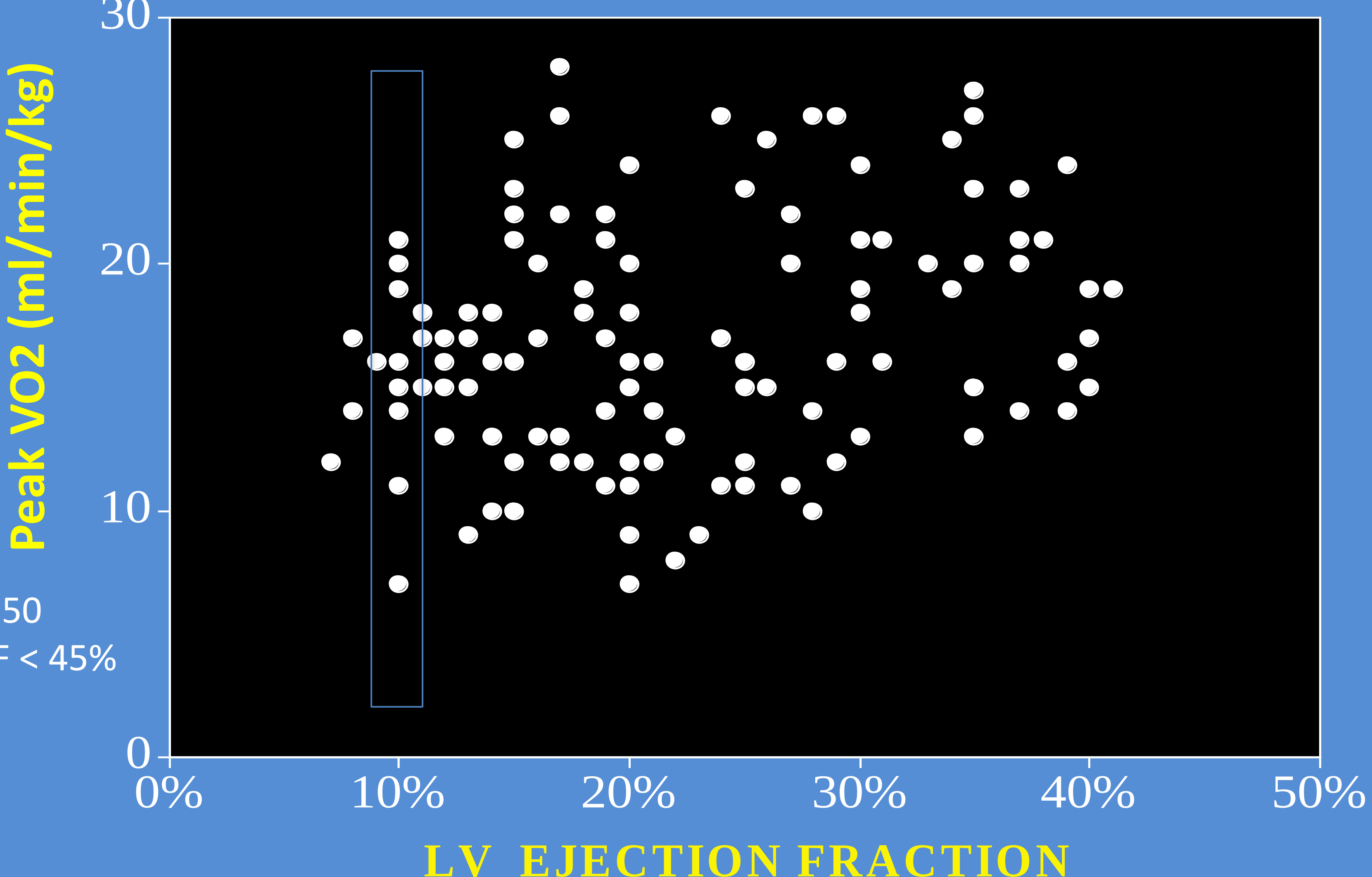
CardioPulmonary Exercise Testing
An haemodynamic test

Alain COHEN SOLAL
Inserm U 942 « MASCOT»
Medical Faculty Paris Cité
Lariboisiere Hospital, Paris

Relationship LVEF/peak VO_2

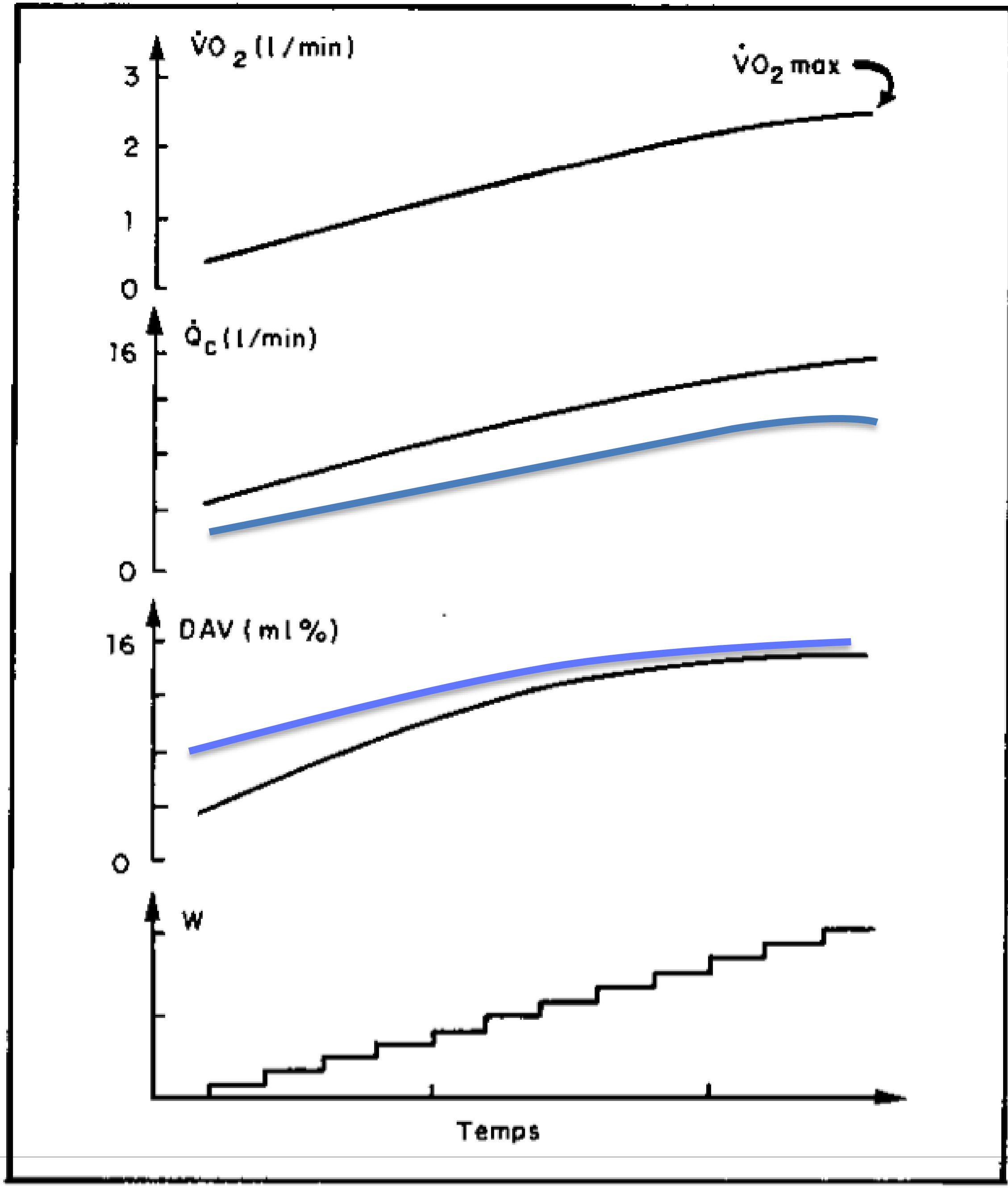
Cohen Solal A. Am J Cardiol 1999



N=150
LVEF < 45%

A brief reminder of physiology
Only a simple one …
The Fick equation

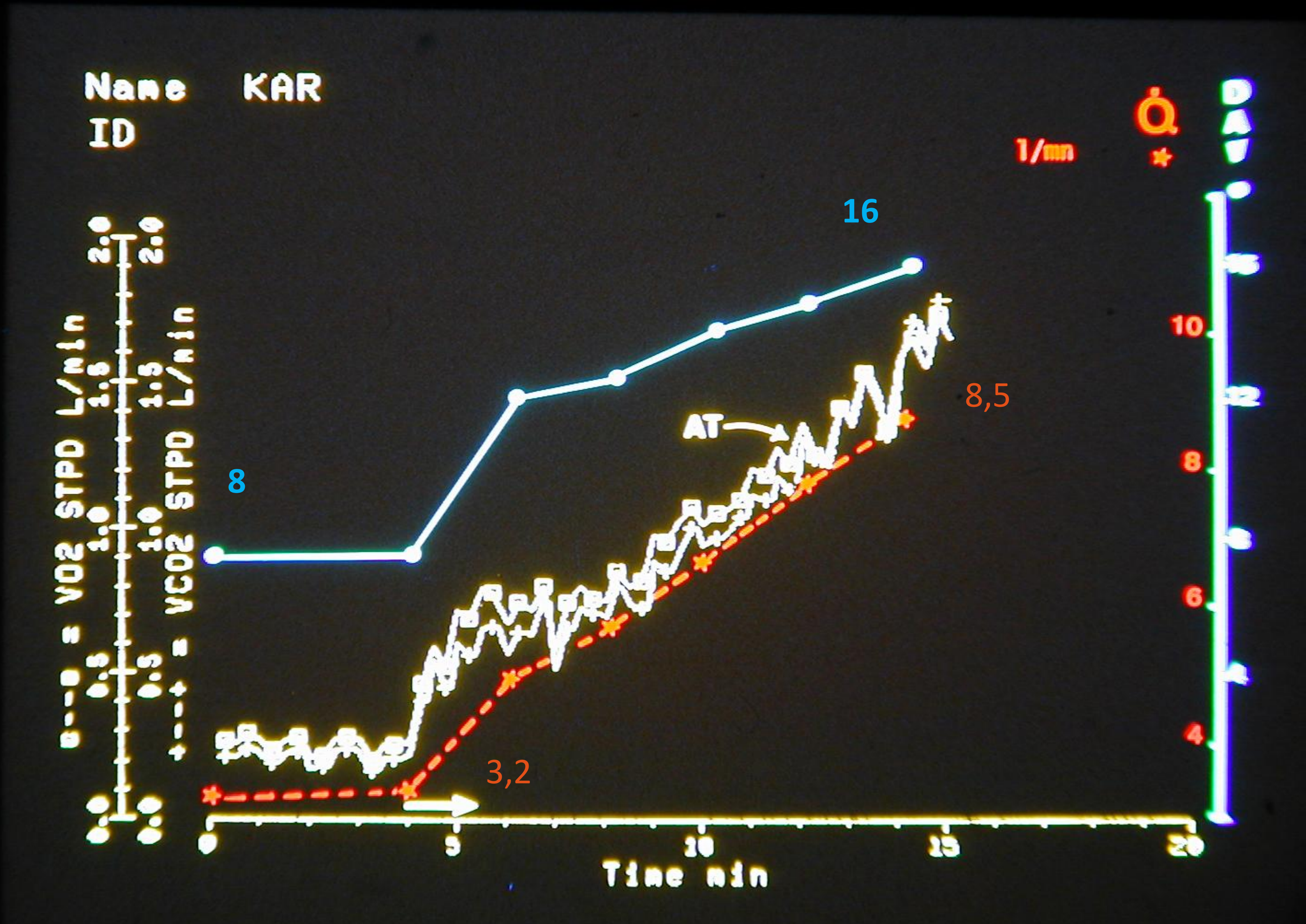
$$VO_2 = CO \times DAV\ O_2$$



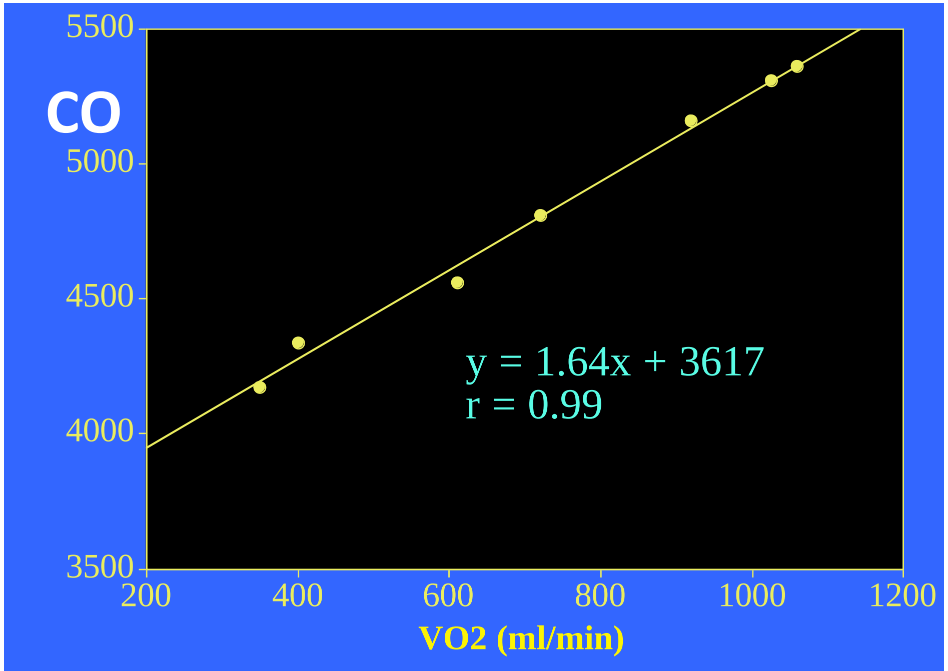
HF

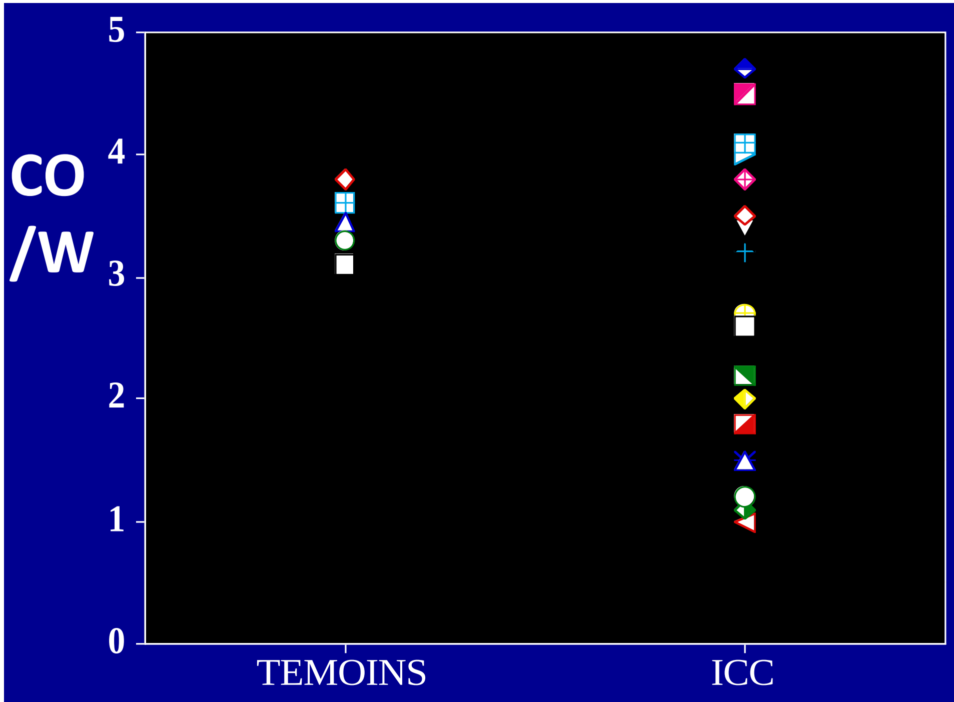
The Fick equation during exercise

Exercise right heart catheterization (1985)

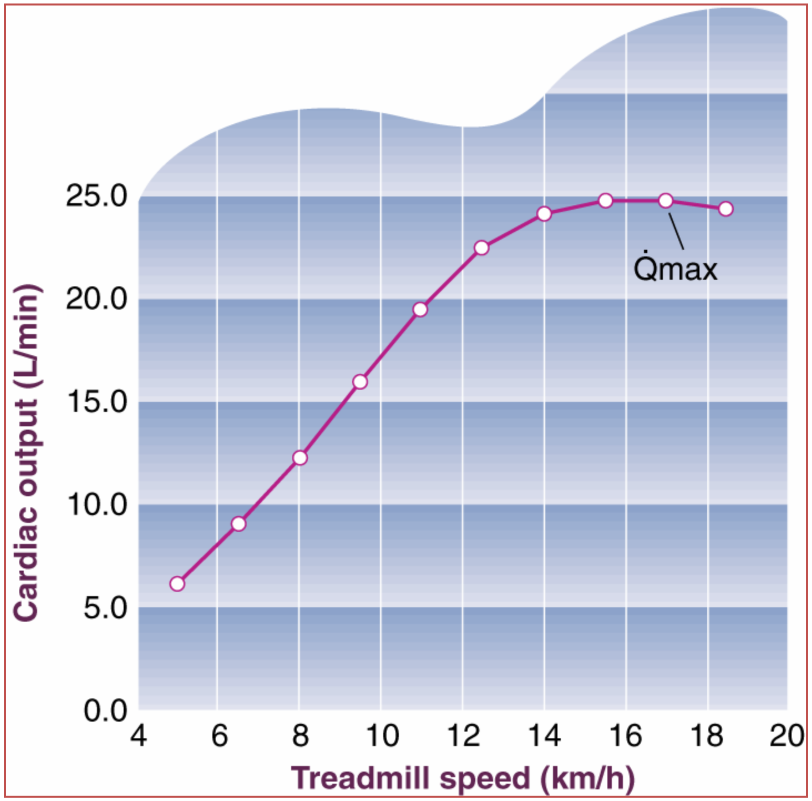


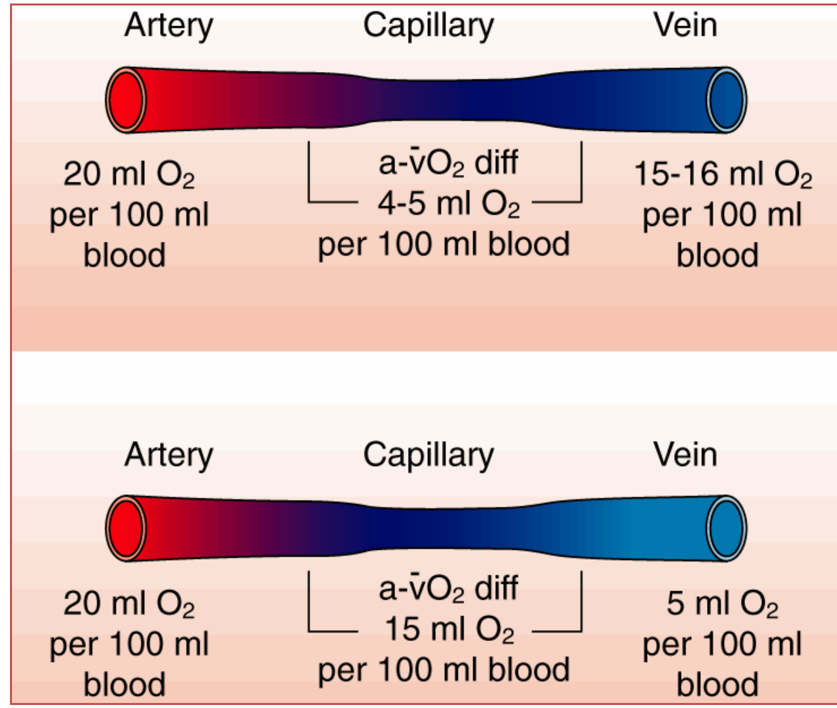
Relationship CO/W





$\Delta\ VO_2 = \Delta\ CO \times \Delta\ AVD\ O_2$

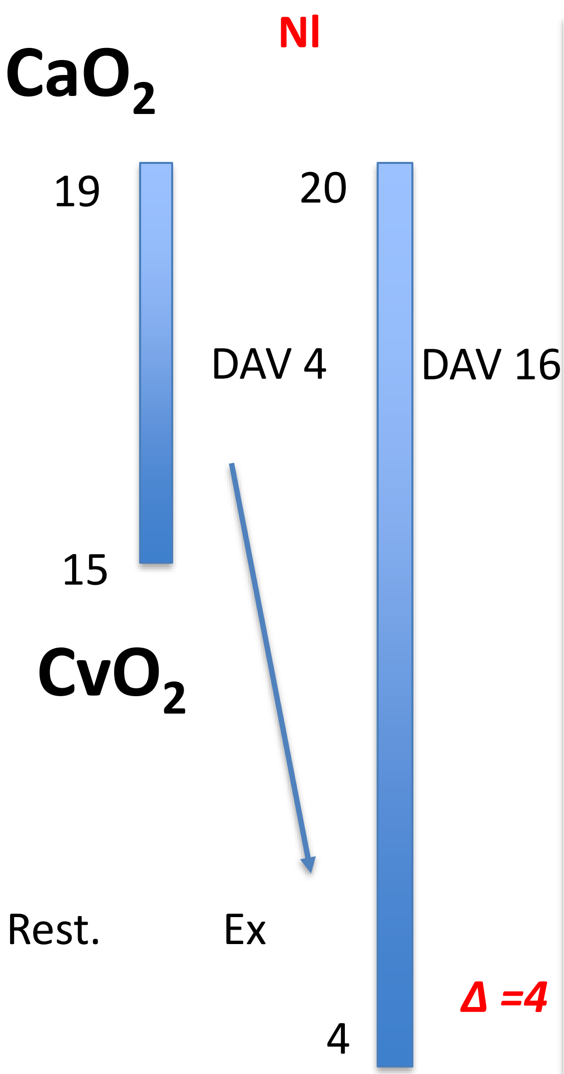




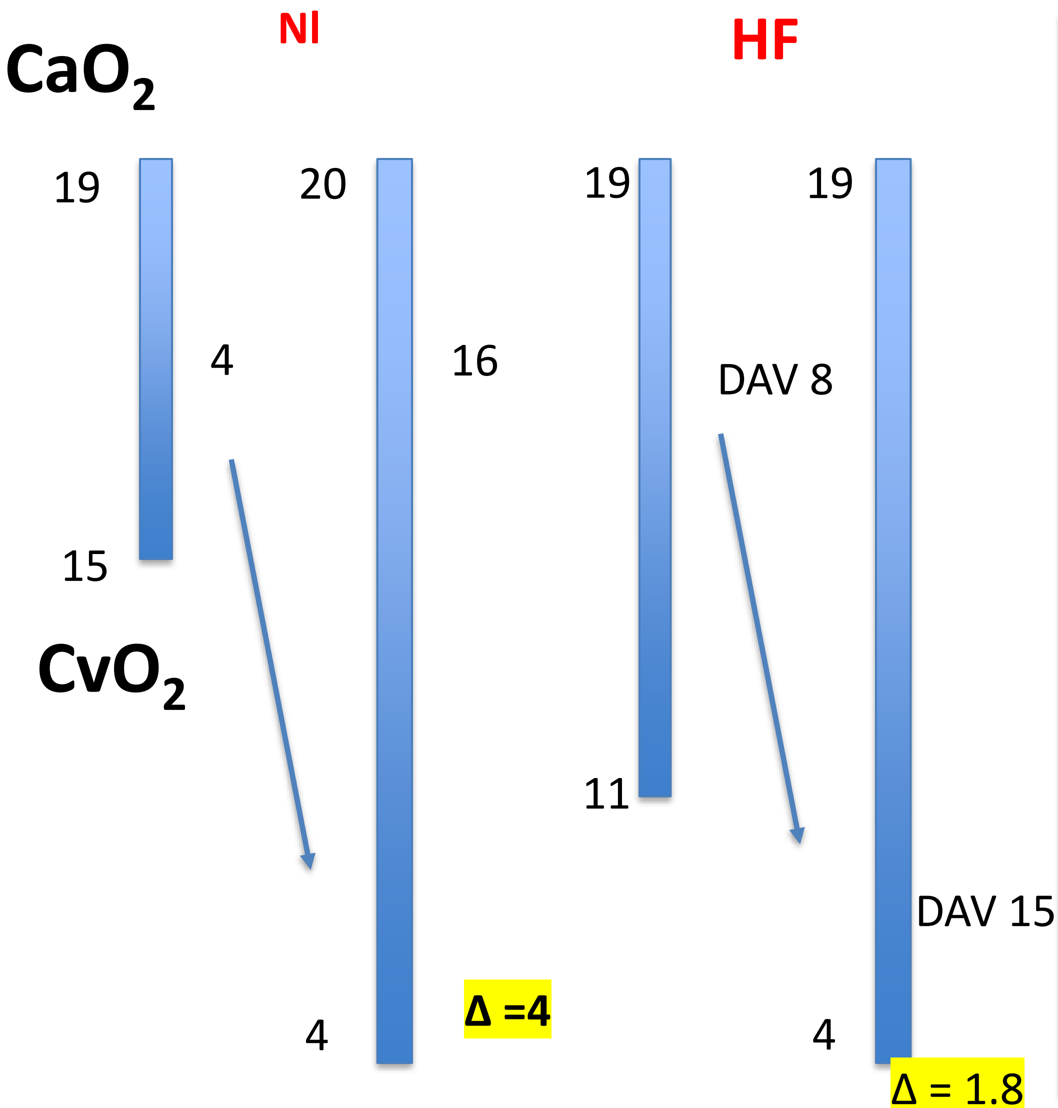
Implications

- It is possible to estimate peak CO from peak VO_2
- If peak VO_2 is 3 500 ml/min and RER (QR) max is 1.20, peak CO is between 23 and 27 l/min
- Peak CO = peak VO_2 / peak AVO_2 difference
- Peak AVO_2 difference is about 0.13-0.16
  - May be increased in athletes or ePO
  - Decreased if
    - Submax exercise
    - Anemia
    - Low muscle bulk (needs engagement of more than 75% of the muscle during exercise; if not, less desaturated blood returning from the rest of the body may decrease peak AVO_2 difference)

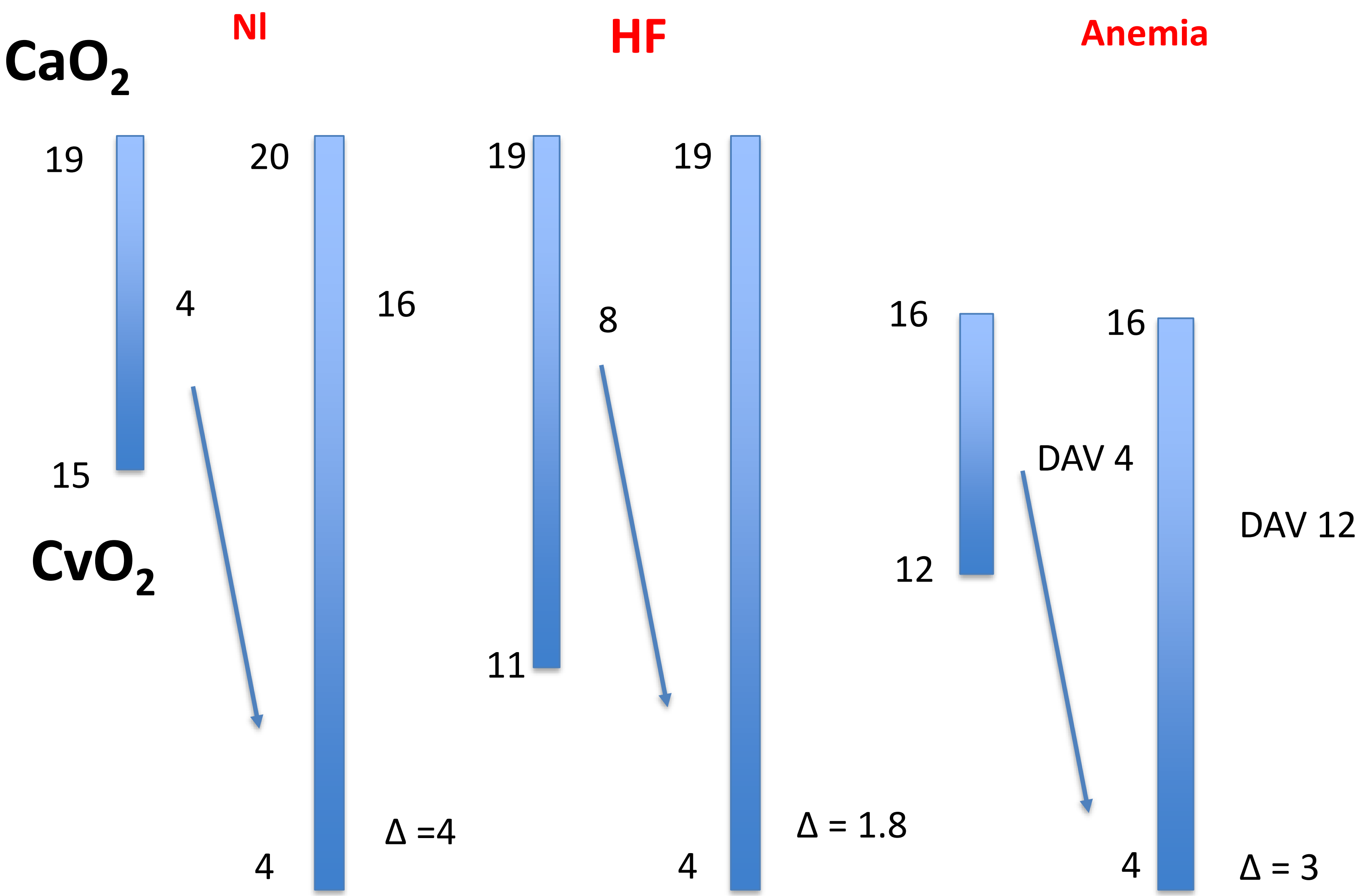
AVO_2 difference responses rest/exercise



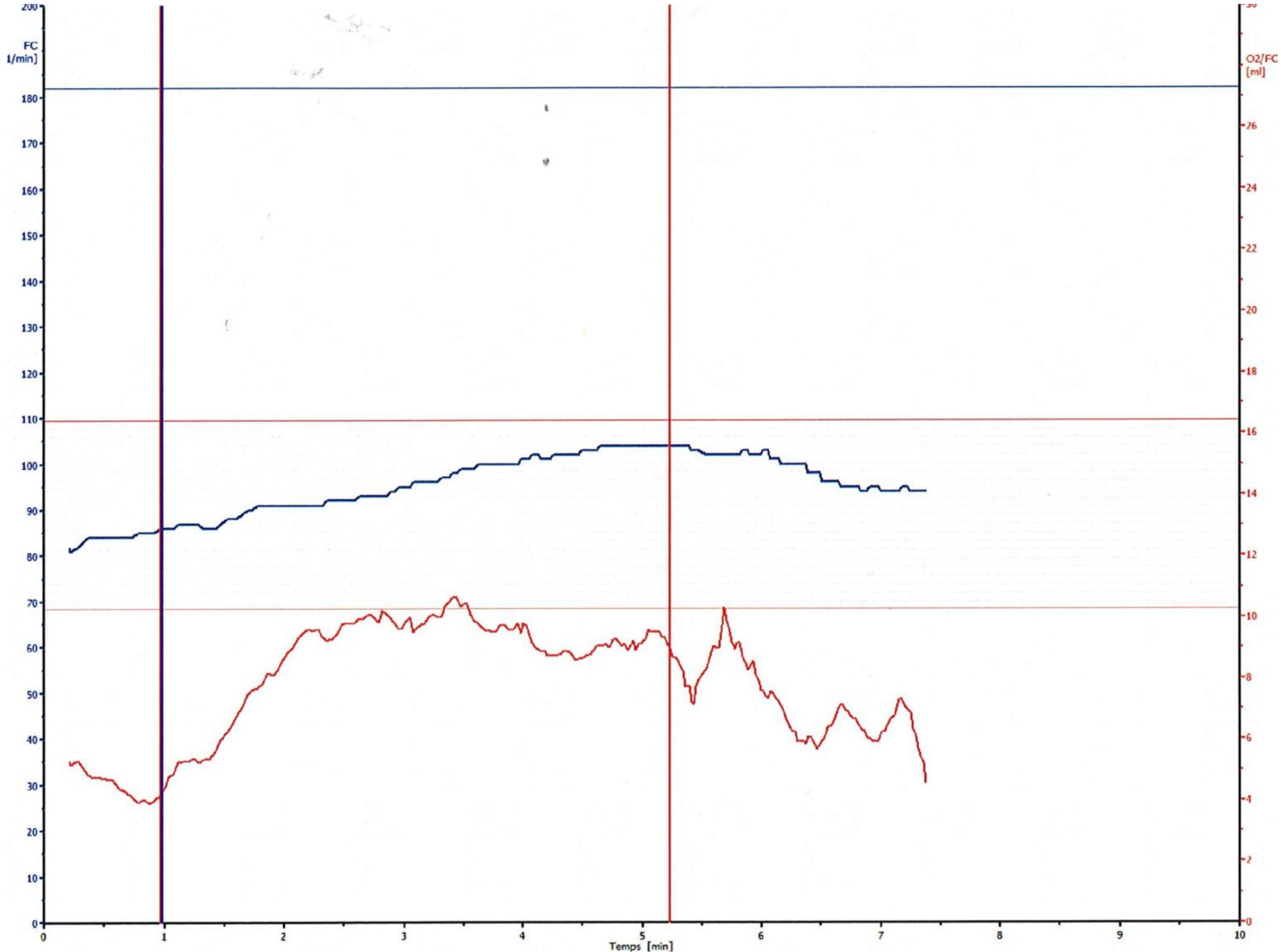
AVO_2 difference responses rest/exercise



AVO$_2$ difference responses rest/exercise



The O_2 pulse



Peak O_2 pulse

- Often a misconception :
  - « O_2 pulse is the reflect of SV »
- O_2 pulse is VO_2/HR = SV x AVO_2 difference
- During exercise:
  - SV
    - May increase by 50-100% in athletes
    - May be stable (normals)
    - May decrease by 30% (HF)
  - AVO_2 difference
    - Always increases
    - X by 5 in athletes
    - X by less than 2 in severe HF (from 8 to 13 …)

Normals /fit people

- If Δ Stroke Volume is 1.5 (+50%)
- If Δ AVO_2 difference is 4 (from 0.04 to 0.16)
- Δ O_2 pulse is 1.5 x 4 = 6
  - So from 4 to 24 for exemple

Severe HF

- If Δ Stroke Volume is 0.8 (20% decrease)
- If Δ AVO_2 is 2 (from 0.06 to 0.12)
- Δ O_2 pulse is 0.8 x 2 = 1.6
- So for example from 4 to 6

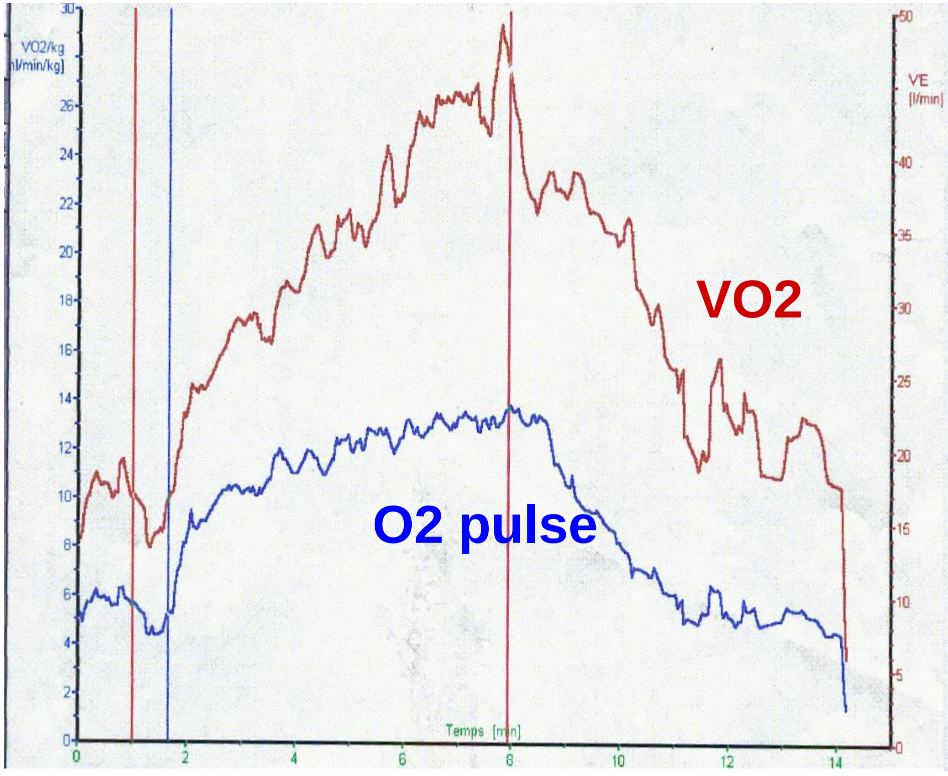
So it is important to consider

- Peak O_2 pulse
  - Normal means normal response
  - Low may be due to low SV or low peak AVO_2 difference
  - By chance, both are often associated ….
  - Normally x 3 at least
- But also the profile
  - Generally regular increase
  - May plateau after 50-75% of the test
  - If early, pathological
    - Suggests a decrease in SV
    - As AVO_2 difference always increases …

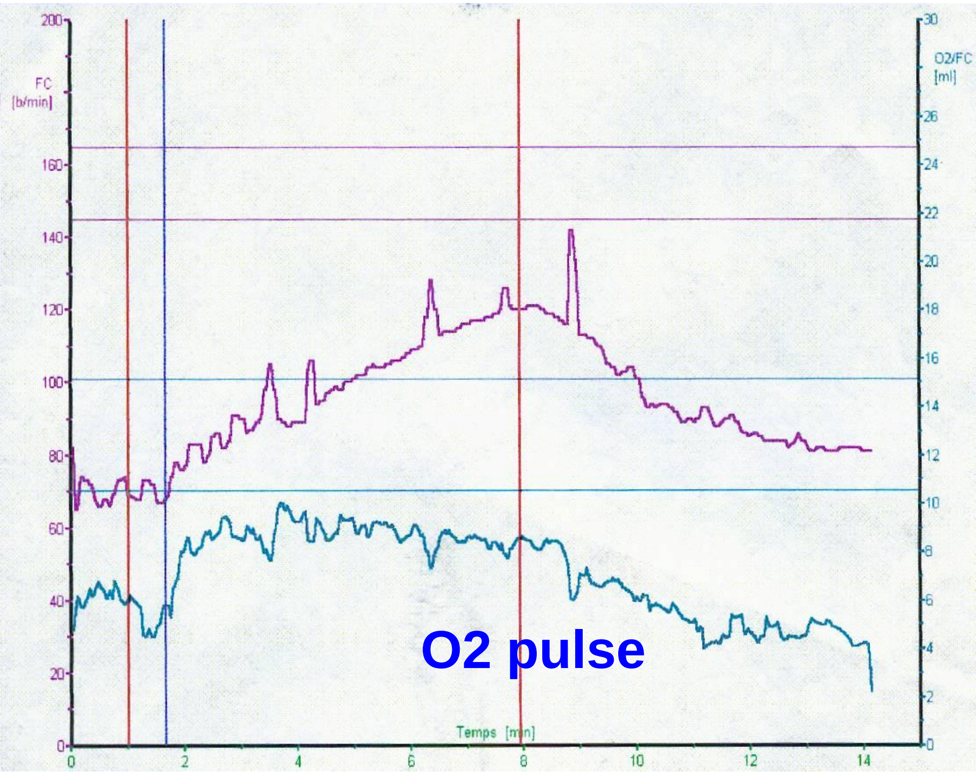
Causes of low Δ O2 pulse

- Anaemia
- O_2 desaturation during exercise (FO reopening)
- Decrease forward flow
  - HF
  - Mitral regurgitation
  - …

O_2 pulse response pattern



Normal



Ischemic HF

O_2 pulse in mitral stenosis

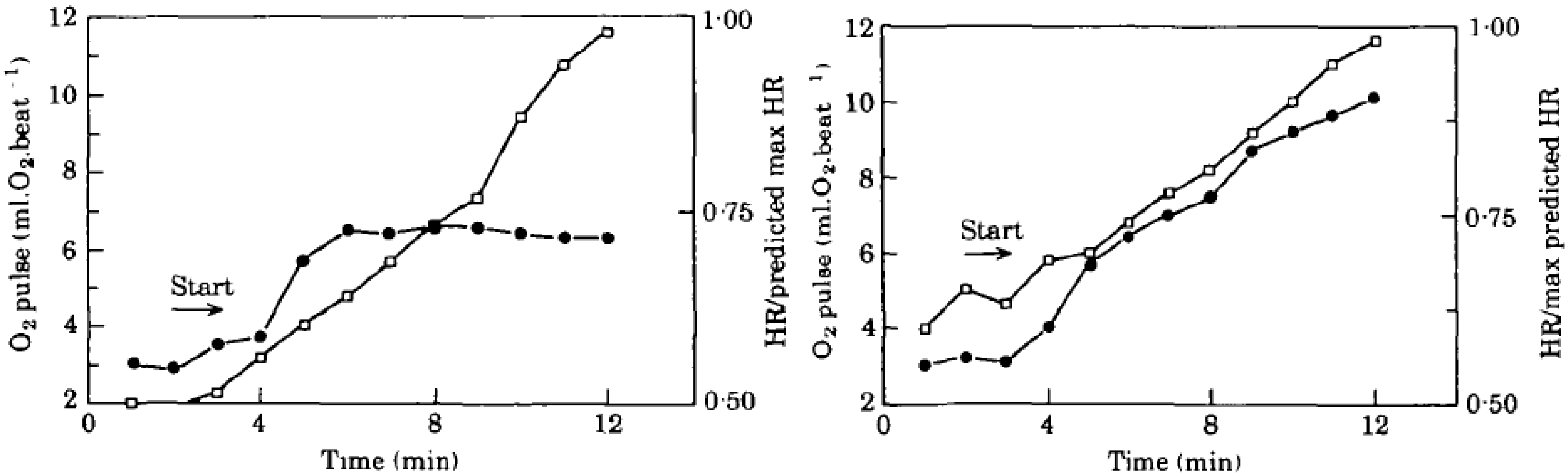
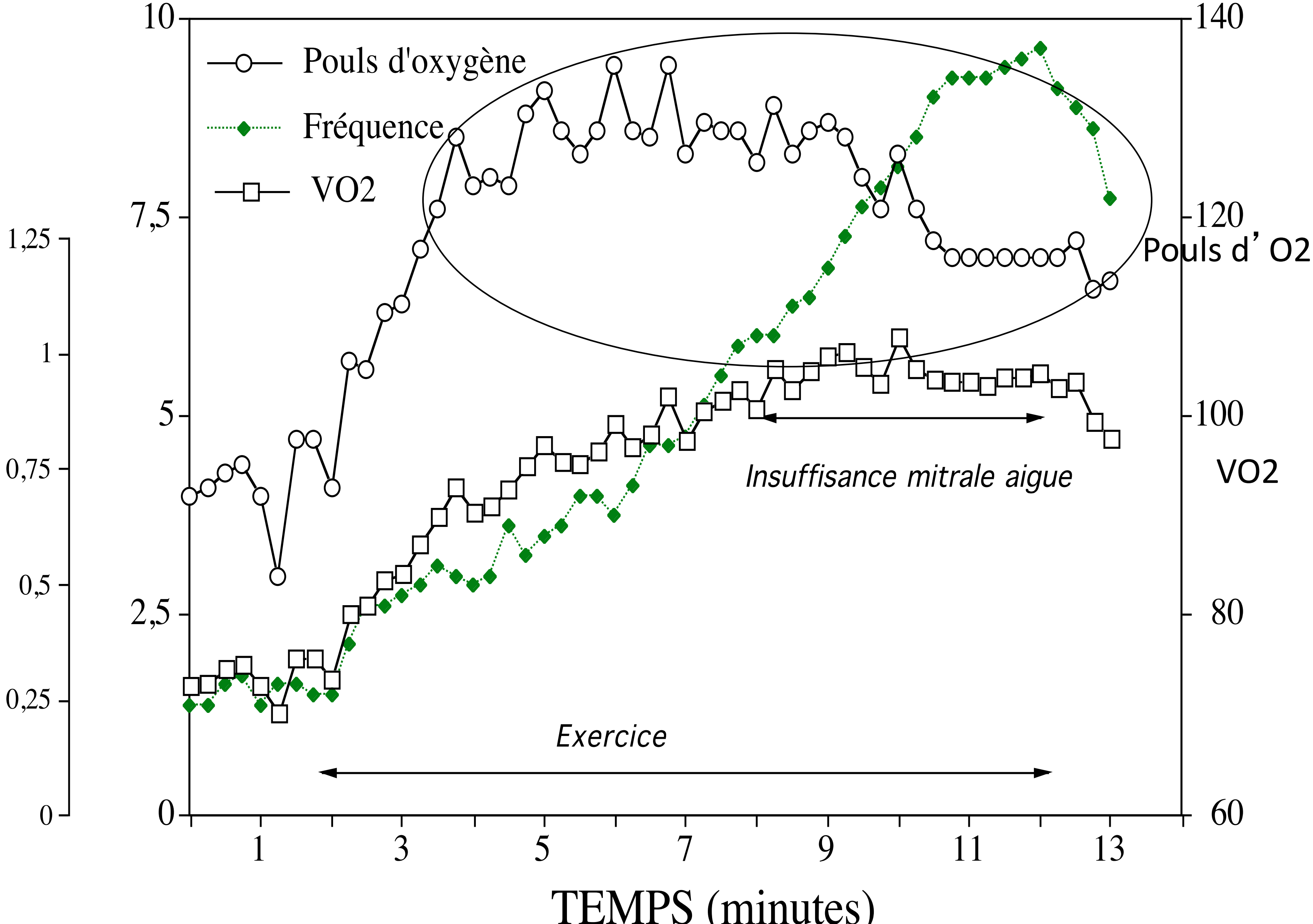


Figure 1 Evolution of the oxygen pulse during exercise in mitral stenosis. The figure displays the evolution of the oxygen pulse (ml oxygen per beat) and the heart rate (expressed in percentage of the predicted maximal heart rate) during exercise in two patients. On the left, the oxygen pulse rapidly plateaued (at the 4th minute of exercise, defined in the study as plateauing=0·40), suggesting a regular decrease of stroke volume during exercise. On the right, the oxygen pulse regularly increased during exercise without any plateau (defined in the study as plateauing=1·00) and the δ oxygen pulse was large (3·3) (too large to be solely explained by an increase of arteriovenous oxygen difference), suggesting the absence of decrease of stroke volume between the beginning and the end of the exercise. ● = O_2 pulse. □ = HR, heart rate.

Cohen Solal A. Eur Heart J 1999

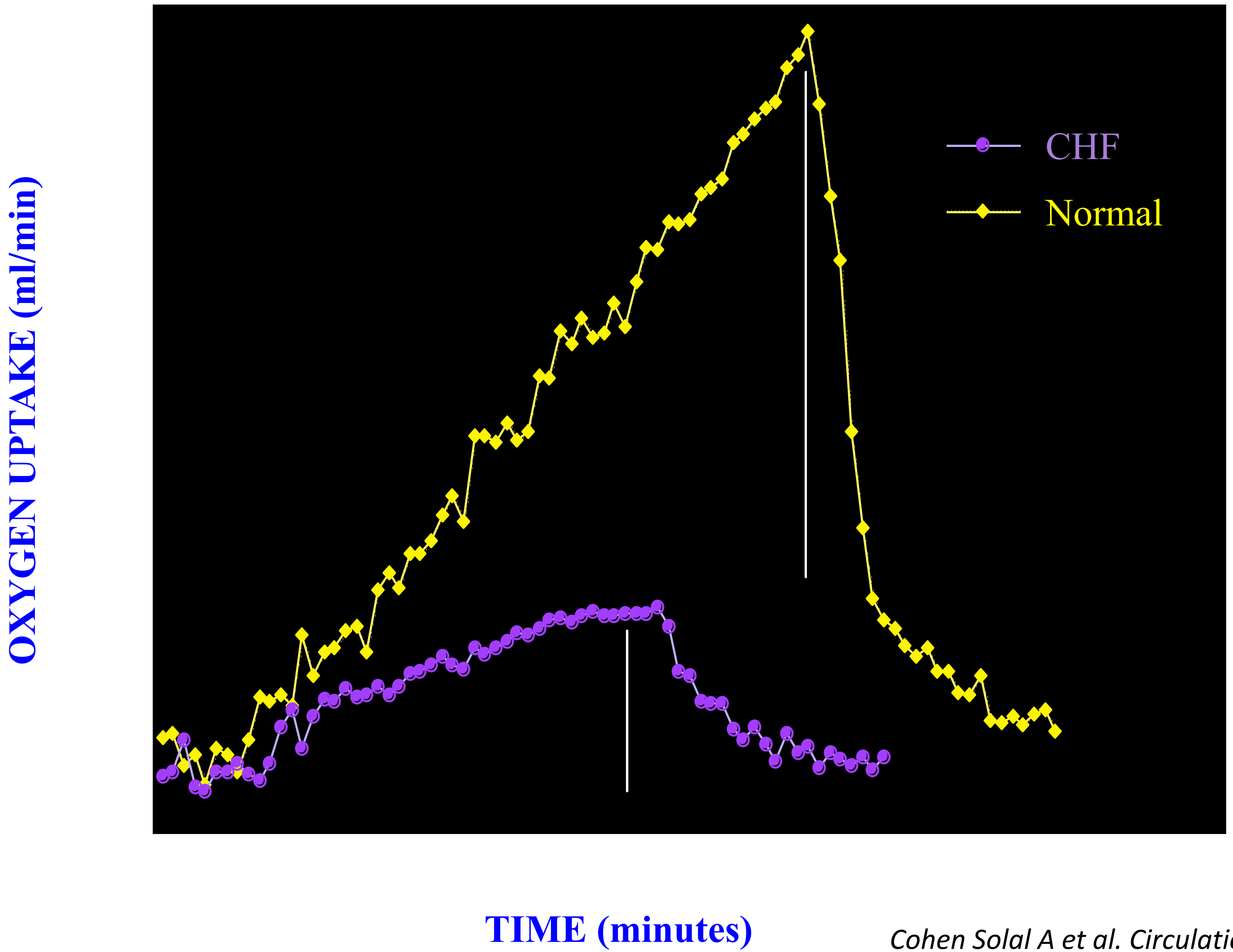
Ischemic mitral regurgitation



Who cares about recovery ? …

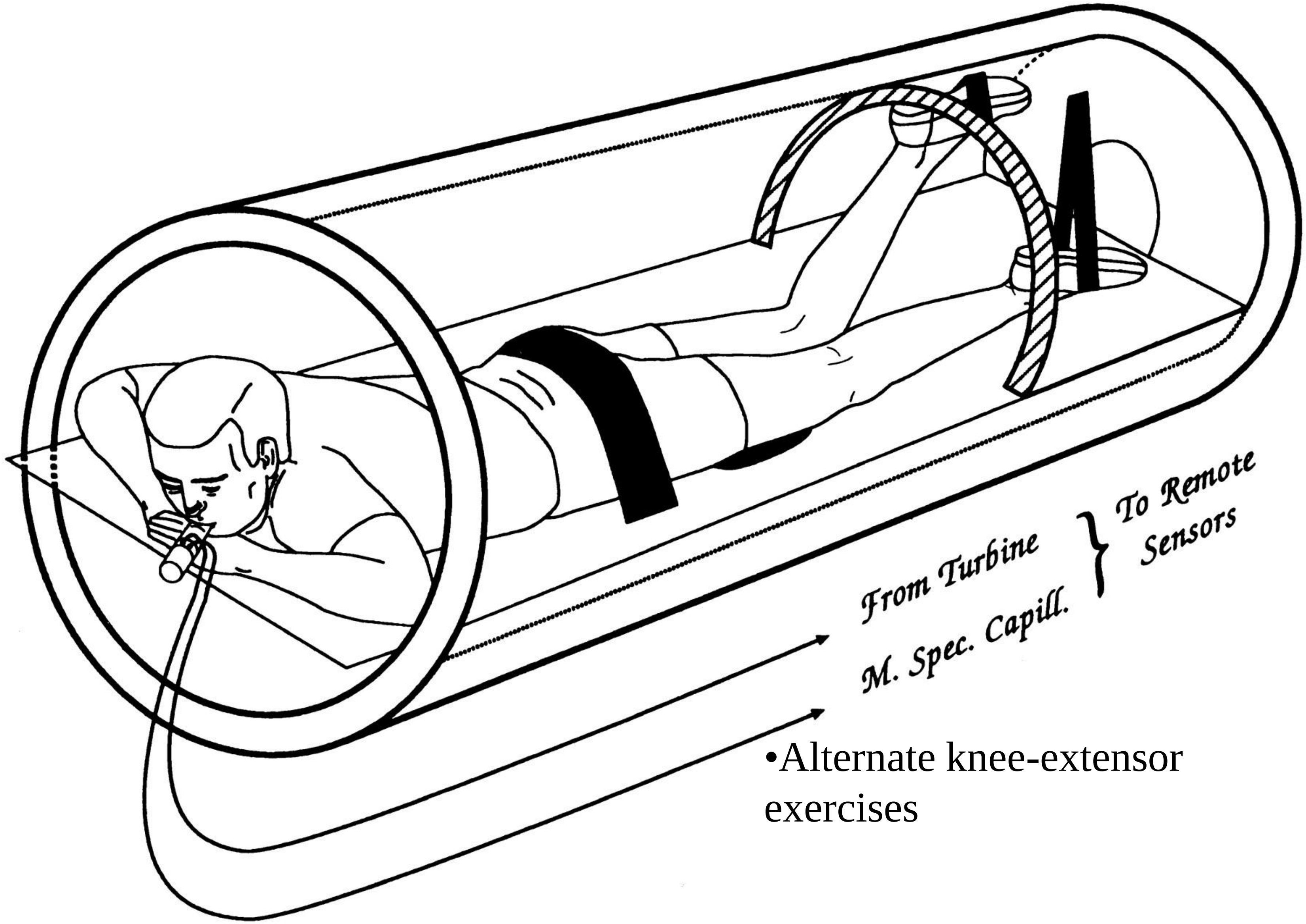
The patient …..

VO2 recovery kinetics



Cohen Solal A et al. Circulation 2002

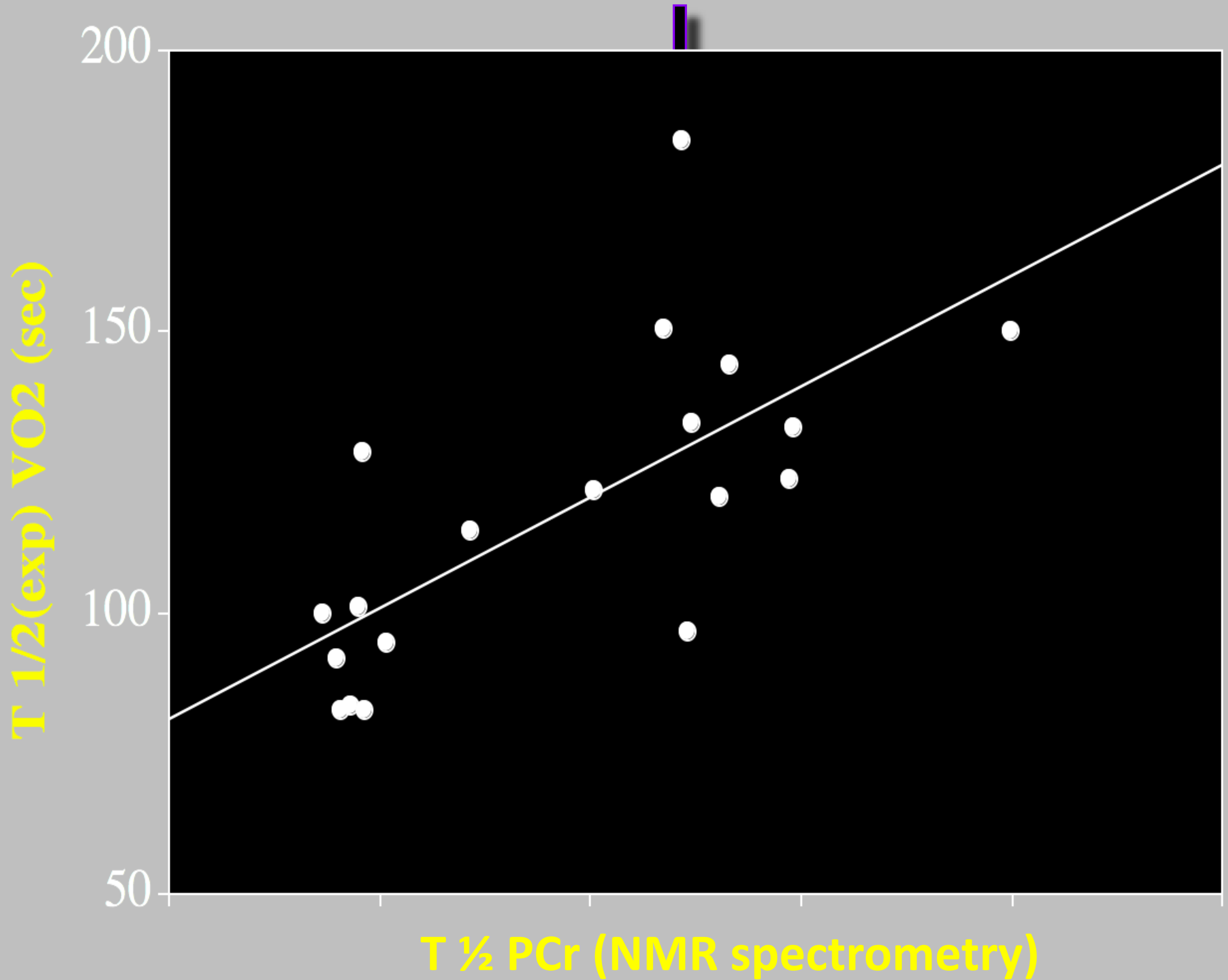
PCr and VO2 kinetics MRI study



•Alternate knee-extensor exercises

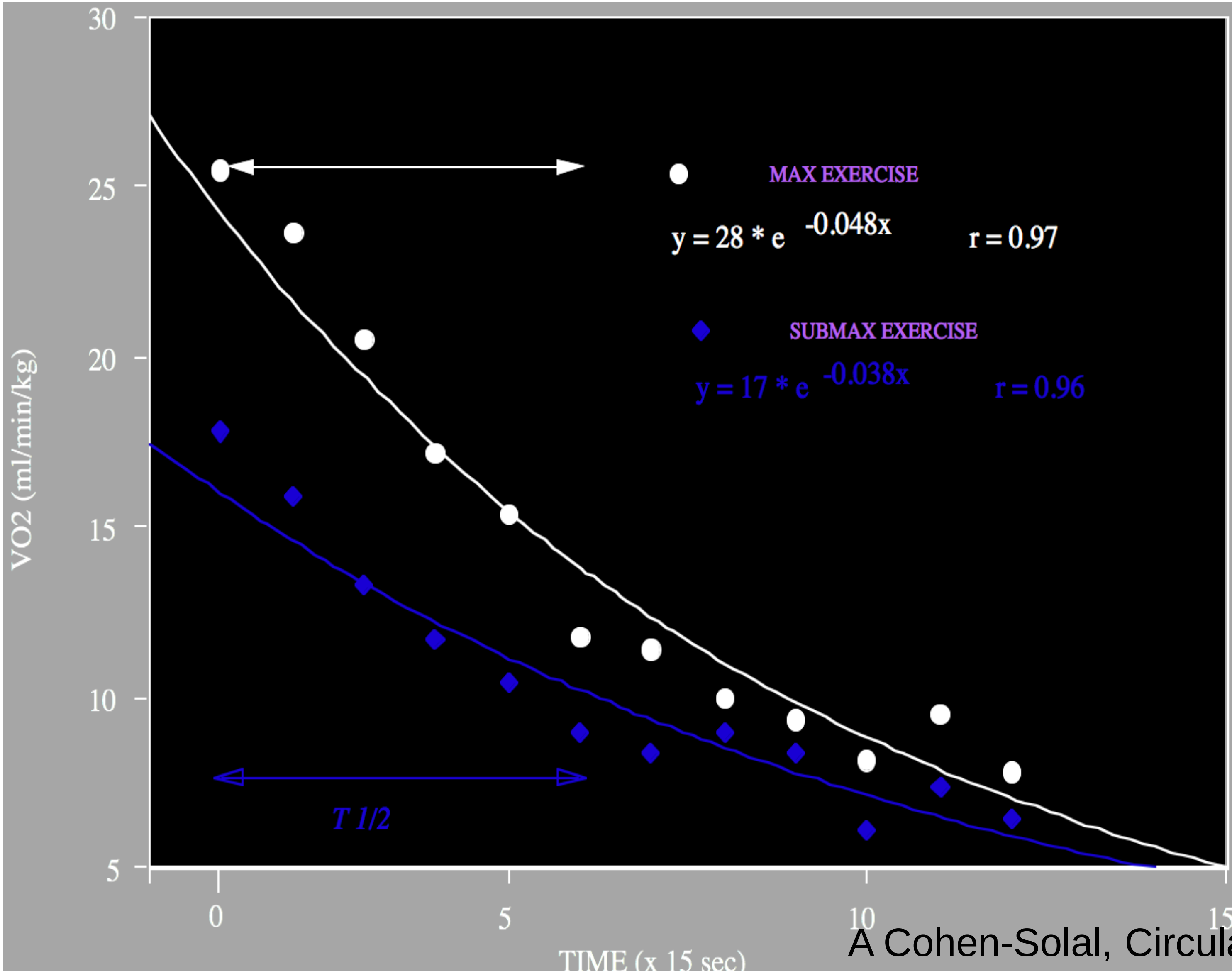
Whipp et al., (1999)

Relationship between VO2 and Pi/PCr kinetics recoveries



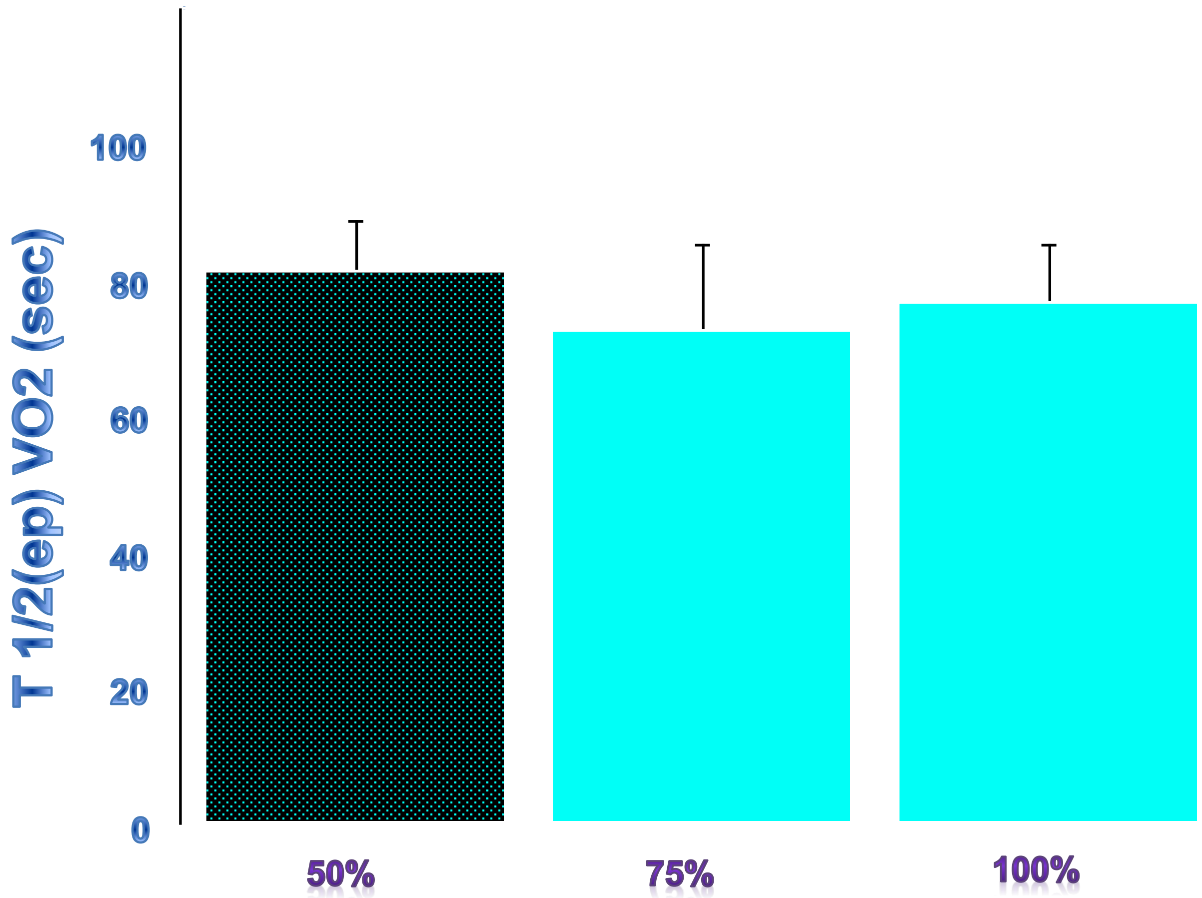
A Cohen-Solal, Circulation 1996

VO2 kinetics recovery : calculation, relation with exercise level



A Cohen-Solal, Circulation 1996

Exercise level and VO2 recovery



Cohen Solal A et al. Circulation 2002

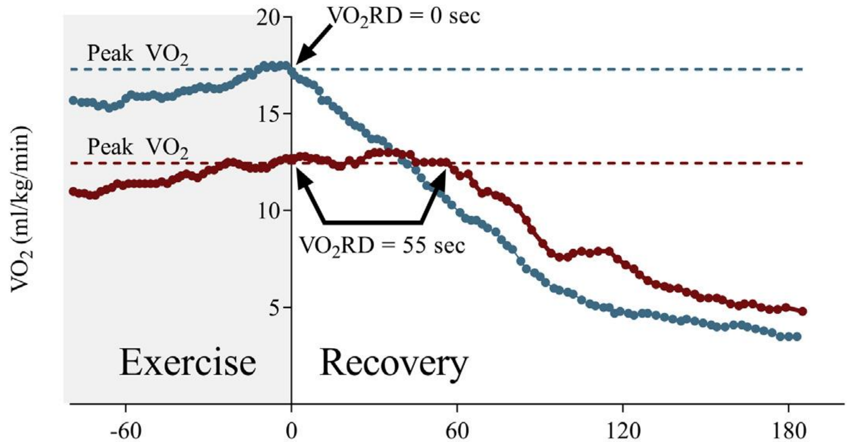
T ½ VO_2 Recovery

- In normal, 80±20 sec
- In HF may exceed 4 minutes …
- If peak VO_2 is low
  - Normal VO2 kinetics recovery : submax test, normal subject
  - Slow VO2 kinetics recovery : circulatory/pulmonary failure
- Prognostic value
- Easy to assess

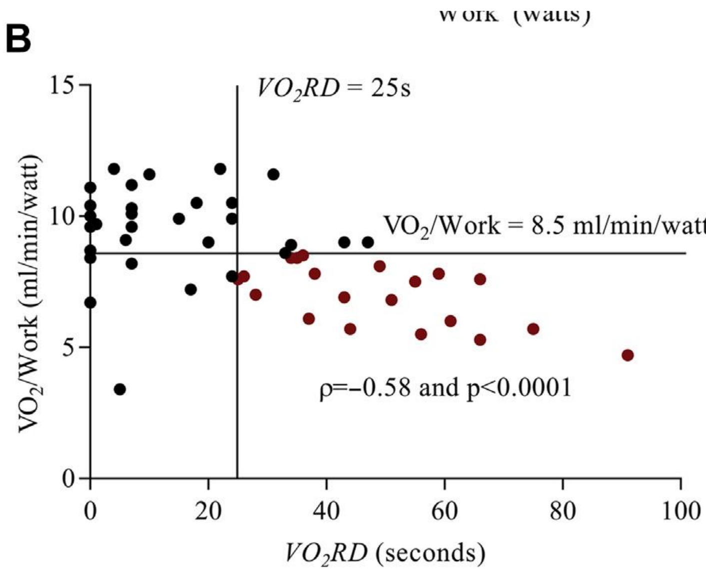
« VO2 RD »

Bailey CS. JACC HF 2018

FIGURE 1 Defining VO_2 Recovery Delay



B



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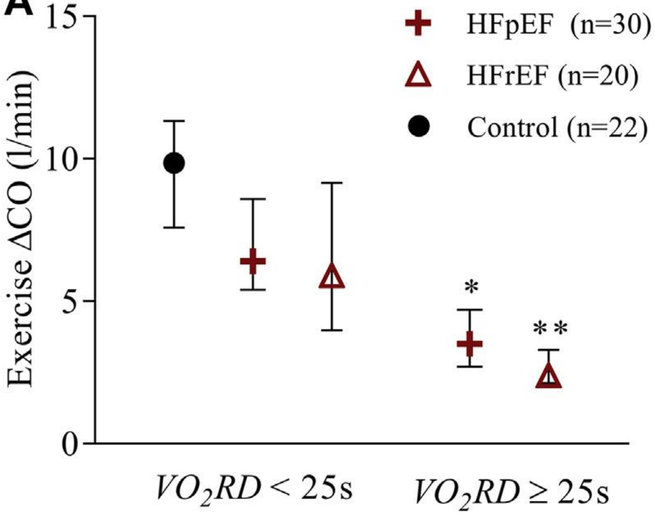

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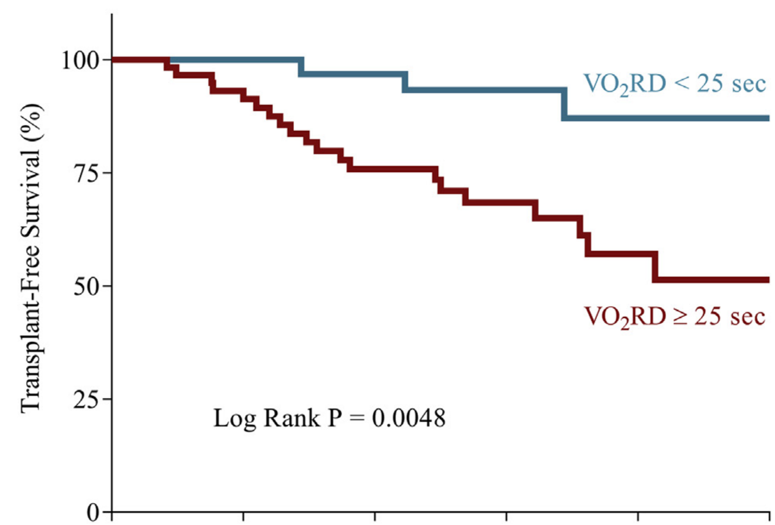
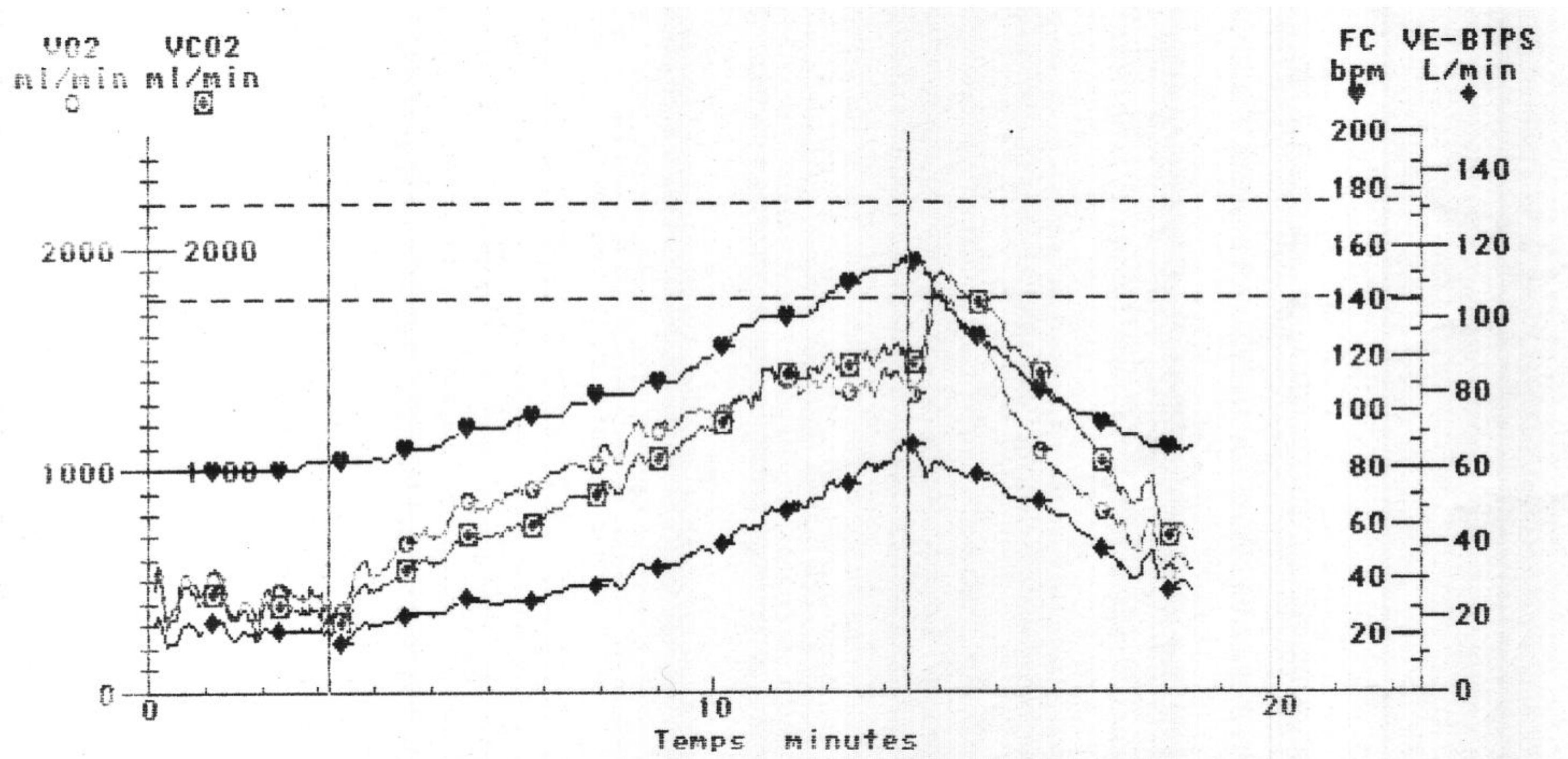


Overshoot at recovery



BP response

- A low BP means a poor exercise circulatory response
- May be observed with preserved peak VO_2
- Coupled analyze of BP and VO_2 can be interesting

BP and « circulatoy power »

- Peak exercise cardiac stroke work and power are major haemodynamic parameters

BP and « circulatory power »

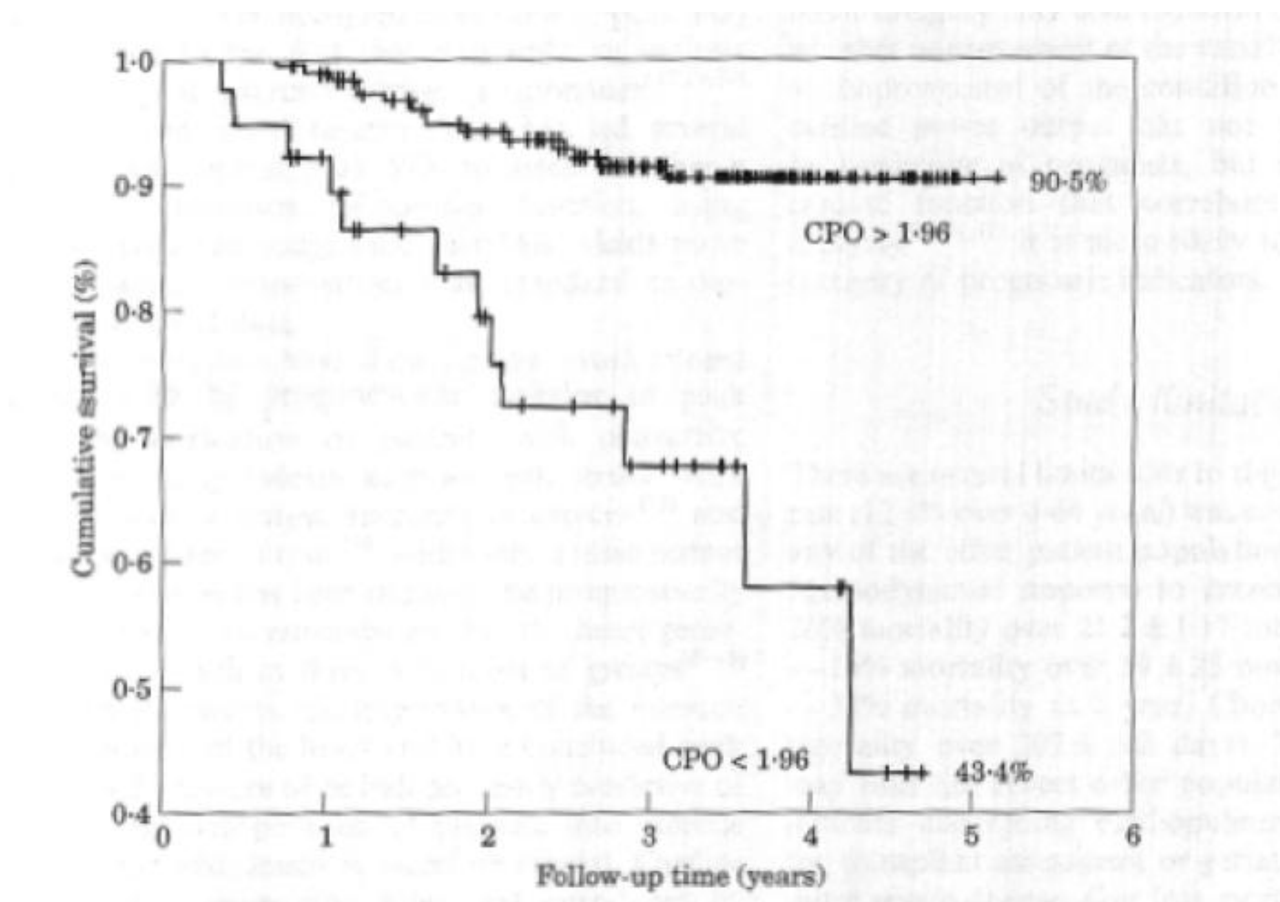
- Peak exercise cardiac stroke work and power are major haemodynamic parameters
- Cardiac power : CO x SBP
  - Better prognostic factor than VO_2max
  - Difficult to assess non invasively during exercise
  - May be approached by CPX : « circulatory power »

Prognostic value of the Stroke Work Index during exercise in CHF

Author	n	Follow up	Results (multivar analy)
Griffin (1991)	49	12 months	SWIex
Roul (1995)	50	21 months	SW ex>VO2ex
Mancini (1996)	65	232 days	SWex>VO2ex
Metra (1999)	219	19 months	SWIex>VO2ex>Na

→ ***Exercise cardiac stroke work : a powerful prognostic factor***

Prognostic value of Cardiac Power Output



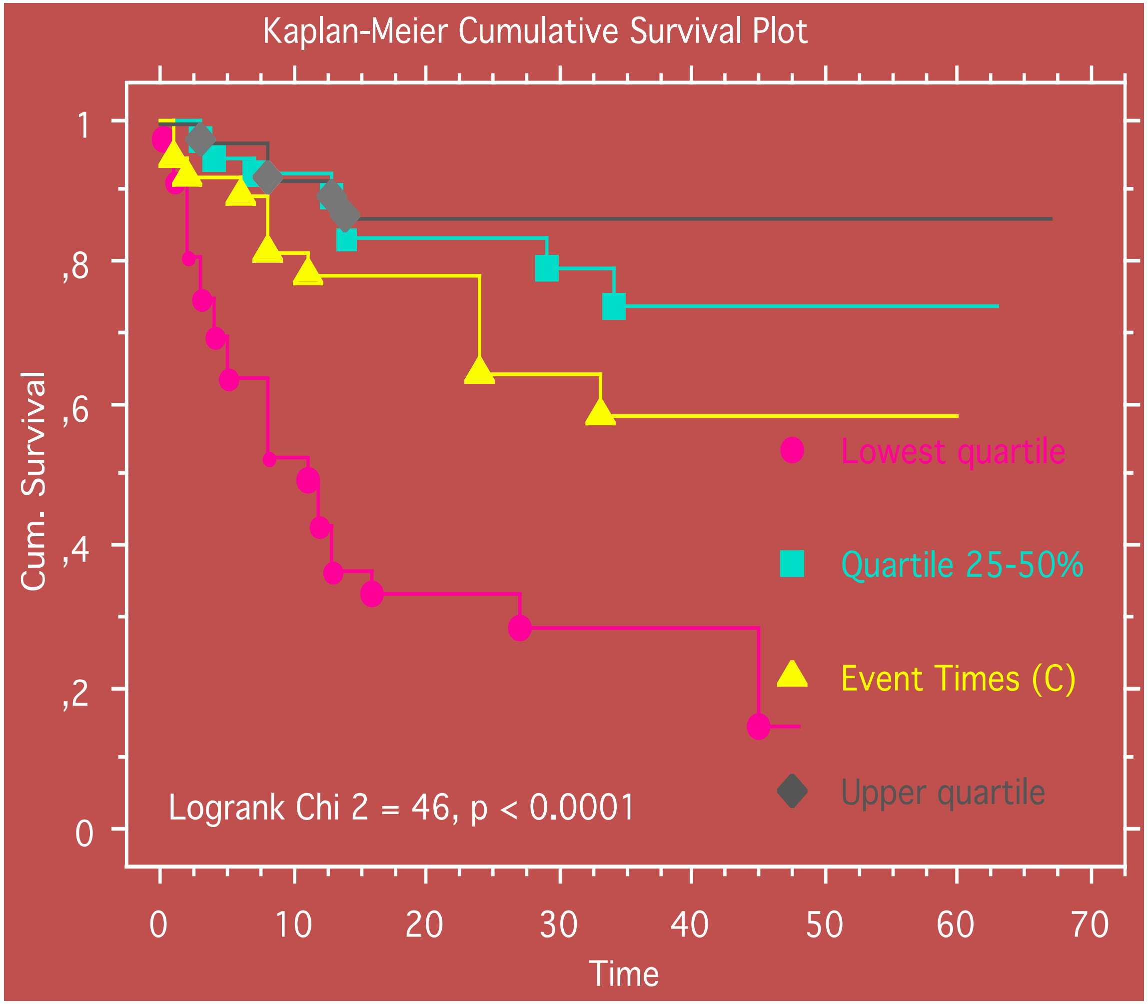
(CO measured by rebreathing method)

LB Tan et al. Eur Heart J 2002

BP and « circulatory power »

- Peak exercise cardiac stroke work and power are major haemodynamic parameters
- Cardiac power : CO x SBP
  - Better prognostic factor than VO2max
  - Difficult to assess non invasively during exercise
  - May be approached by CPX : « circulatory power »
- Circulatory power
  - VO2max x SBP max
  - = CO max x AVO_2D max x SBP max
  - = ***CO max x SBP max*** x AVO_2Dmax
  - = Max Cardiac Power x AVO_2D max

Survival according to quartiles of Circulatory Power



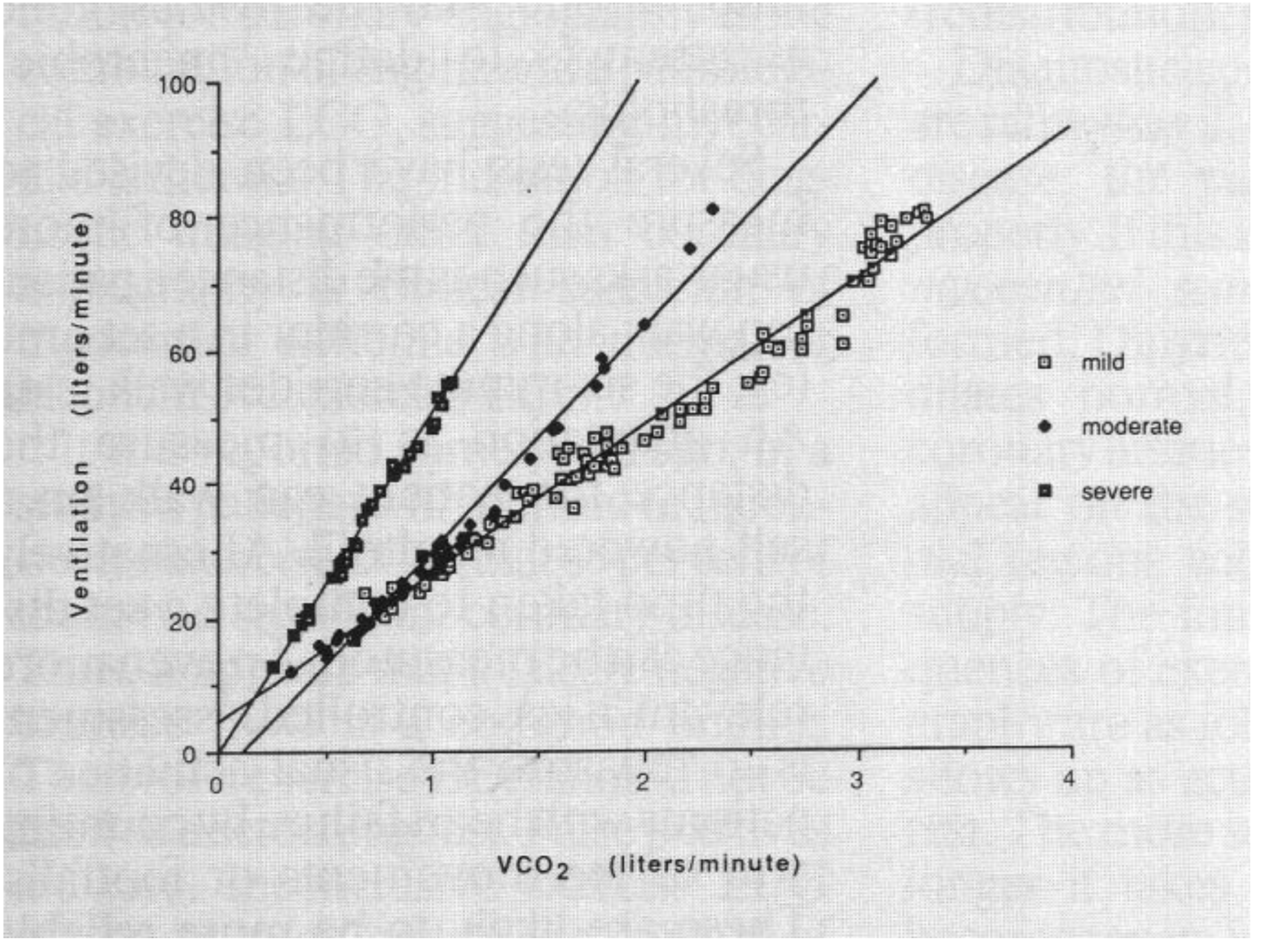
Tabet JY et al.
EHJ 2002

Only predictor of survival by multivariate analysis

VE/VCO_2 slope

- Reflects the amount of ventilation needed to reject CO_2
- Normally, 25-30 l/min of ventilation for expiring 1 litre of CO_2
- (so normal VE/VCO_2 slope 25-30)
- (Age dependent)

VE/VCO2 slope during exercise in CHF



Meaning of an increase in VE/VCO_2 slope

- Complex, multiple causes
  - Increased dead space (rapid superficial breathing)
  - Insufficient increase in pulmonary blood flow (V/P mismatch)
  - Abnormalities of chemoreceptors (hyper responsiveness)
  - Ergoreflex (stimulation of ventilation from nerval stimulation arising from the pathological peripheral muscles)
- High prognostic value in CHF

Clinical and Hemodynamic Correlates and Prognostic Value of VE/VCO_2 Slope in Patients With Heart Failure With Preserved Ejection Fraction and Pulmonary Hypertension

SEBASTIAAN H. C. KLAASSEN, BSc, LICETTE C. Y. LIU, MD, PhD, YORAN M. HUMMEL, PhD, KEVIN DAMMAN, MD, PhD, PETER VAN DER MEER, MD, PhD, ADRIAAN A. VOORS, MD, PhD, ELKE S. HOENDERMIS, MD, PhD, AND DIRK J. VAN VELDHUISEN, MD, PhD

Groningen, The Netherlands

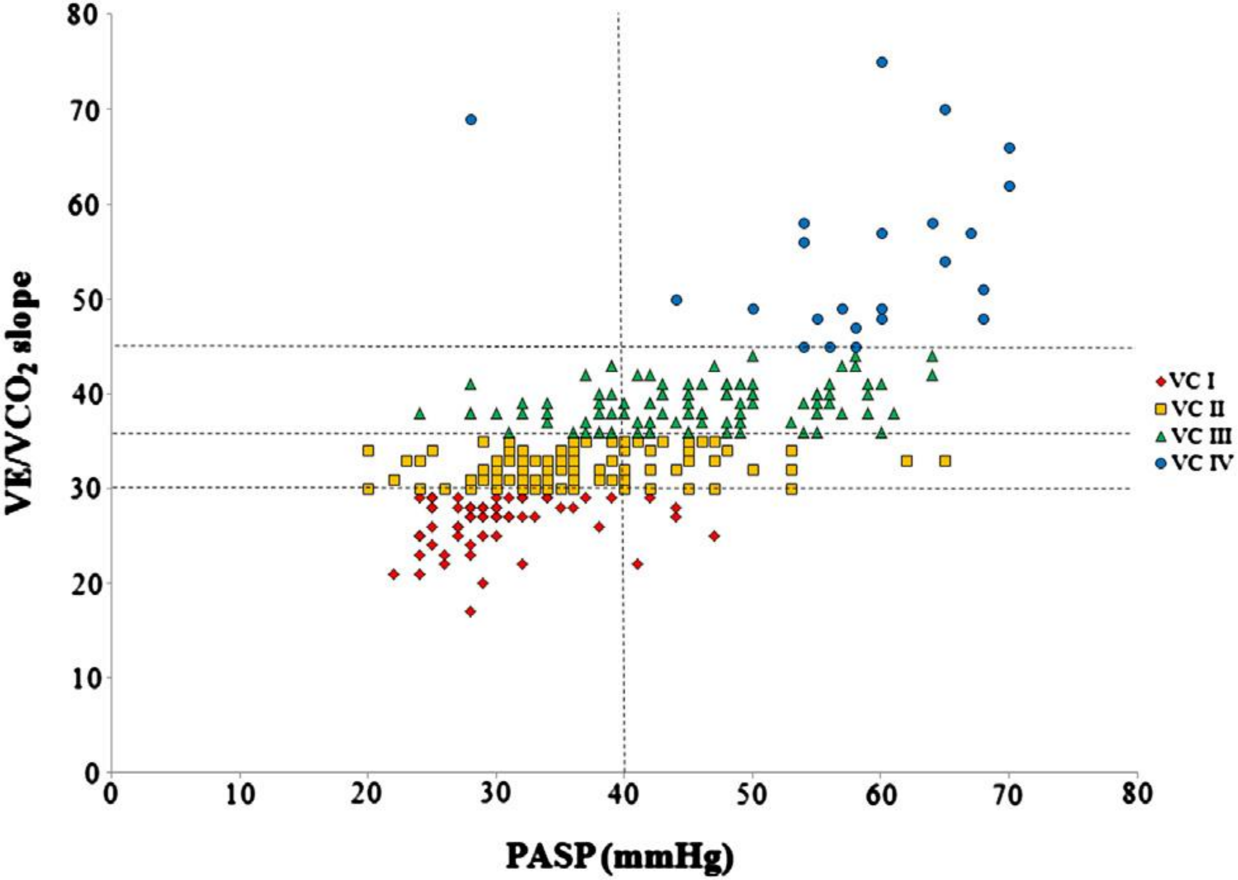
Table 4. Regression: Correlation With the VE/VCO_2 Slope

	Univariate Correlation Coefficients	*P* Value	Model 1	*P* Value
mPAP	0.287	.002	0.233	.027
sPAP	0.172	.003	0.134	.042
PVR	0.019	.002	0.015	.024
RVS	0.175	.002	0.134	.041
LVS	–0.123	.008	–0.107	.030
Sodium	–0.494	.092	–	–
Diuretic use	3.723	.091	–	–
Log NT-proBNP	0.917	.127	–	–
NYHA functional class	2.873	.145	–	–
Log urea	2.111	.173	–	–
Age	–0.130	.222	–	–
Sex	–2.084	.308	–	–
β-Blocker use	0.453	.847	–	–
LVED	–0.160	.281	–	–
PCWP	0.061	.704	–	–

Model 1: adjusted for log NT-proBNP and age. Abbreviations as in Tables 1 and 3.

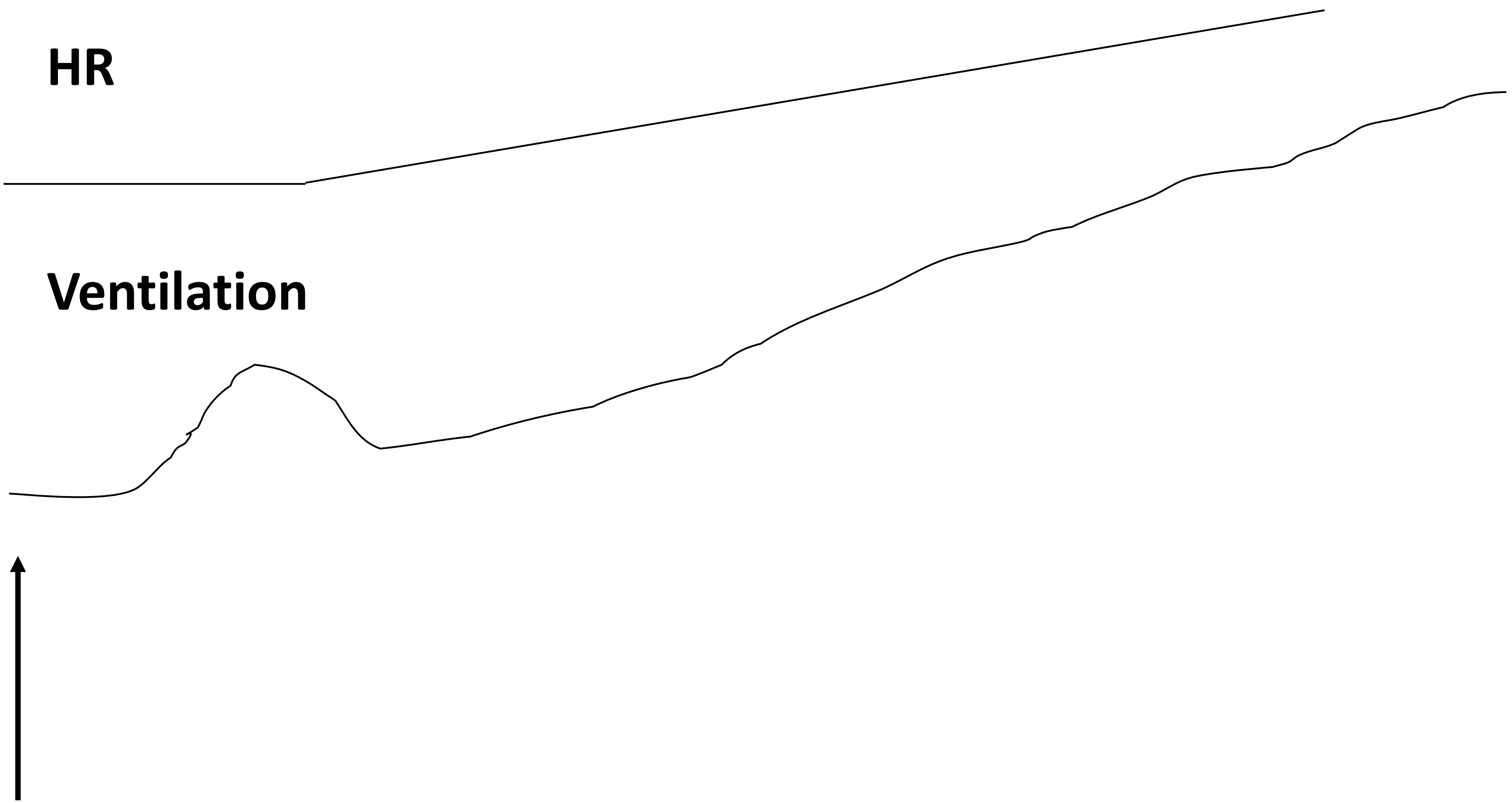
VE/VCO_2 slope and SPAP in HF

VE/VCO2 > 45 = PHT
VE/VCO2 < 30 = no PHT
VE/VCO2 30-45 : grey zone



Guazzi M et al.
J Cardiac Fail 2013;19:461e467)

CPX and chronotropic incompetence a specific CPX profile



Prognostic value

FOCUSED PERSPECTIVE

Exercise Capacity

The Prognostic Variable That Doesn't Get Enough Respect

Daniel B. Mark MD, MPH; Micheal S. Lauer, MD

Circulation

So don’t forget

- CPX IS an haemodynamic test
- That deeply goes into pathophysiology

Clinical cases

Case 1

- 50 years
- DCM LVEF 20%
- NYHA I
- LBBBB

06-OCT-2002 23:37:02 BABIC, SVETOZAR ID: 000000000005

25mm/s
10mm/mV
40Hz

20W/1MN/1
RECUP
FC: 128bpm

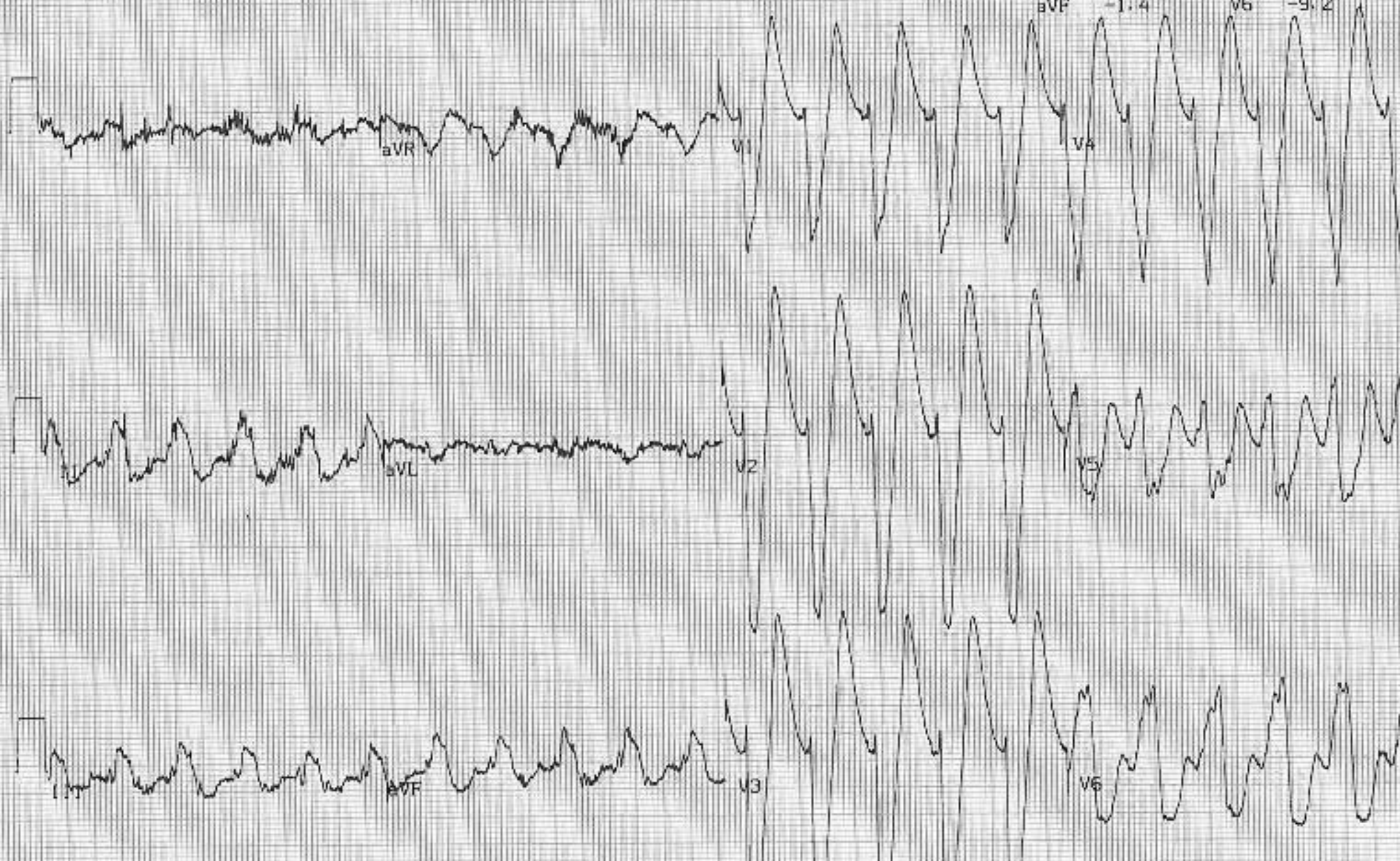
REAPPR. à EFFORT 06:29

Rapport 12 dérivat ns
Chrono 1: 07:21
Chrono 2: 00:18
Travail:0Watts

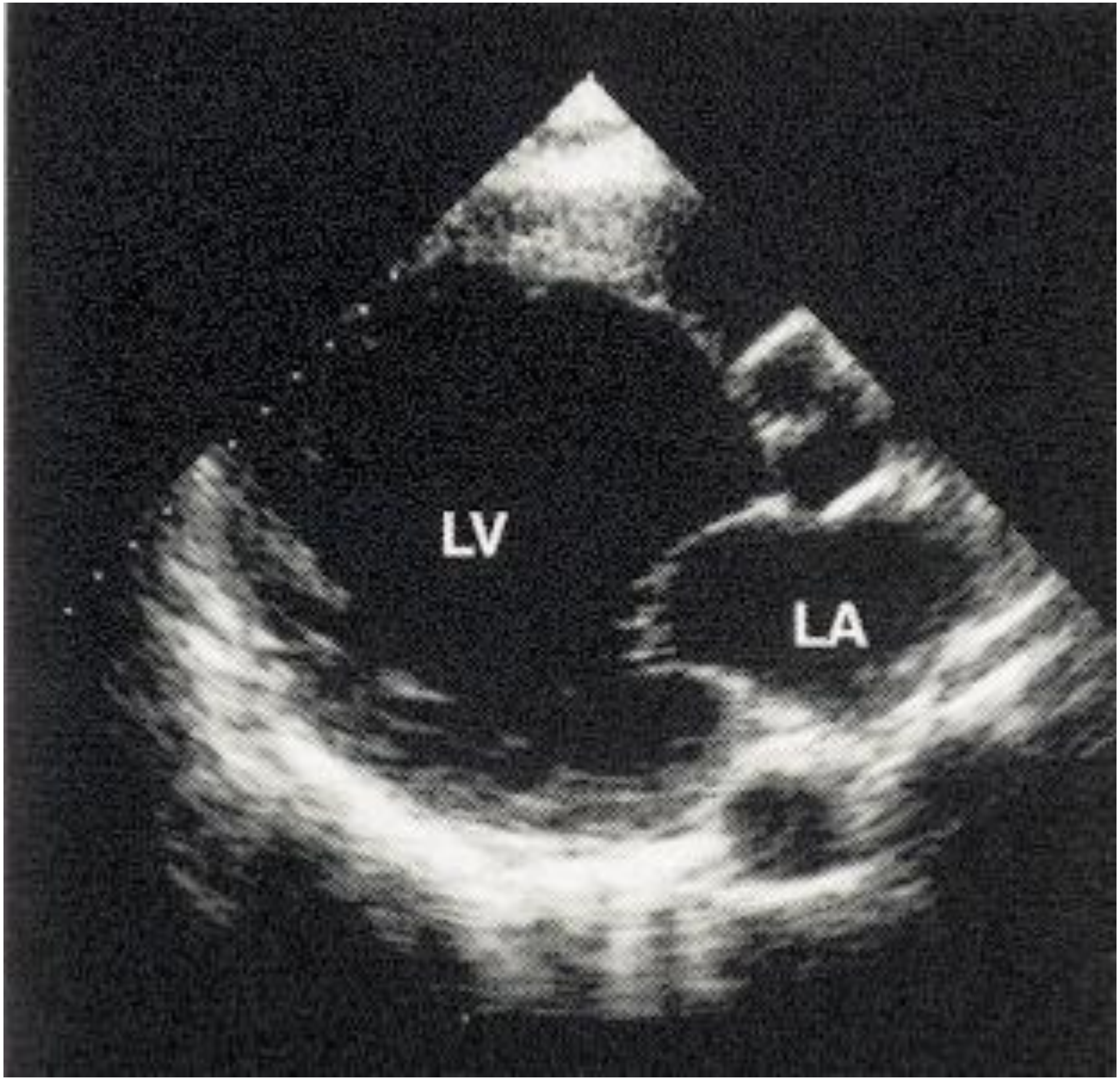
HOPITAL BEAUJON 92 CLICHY

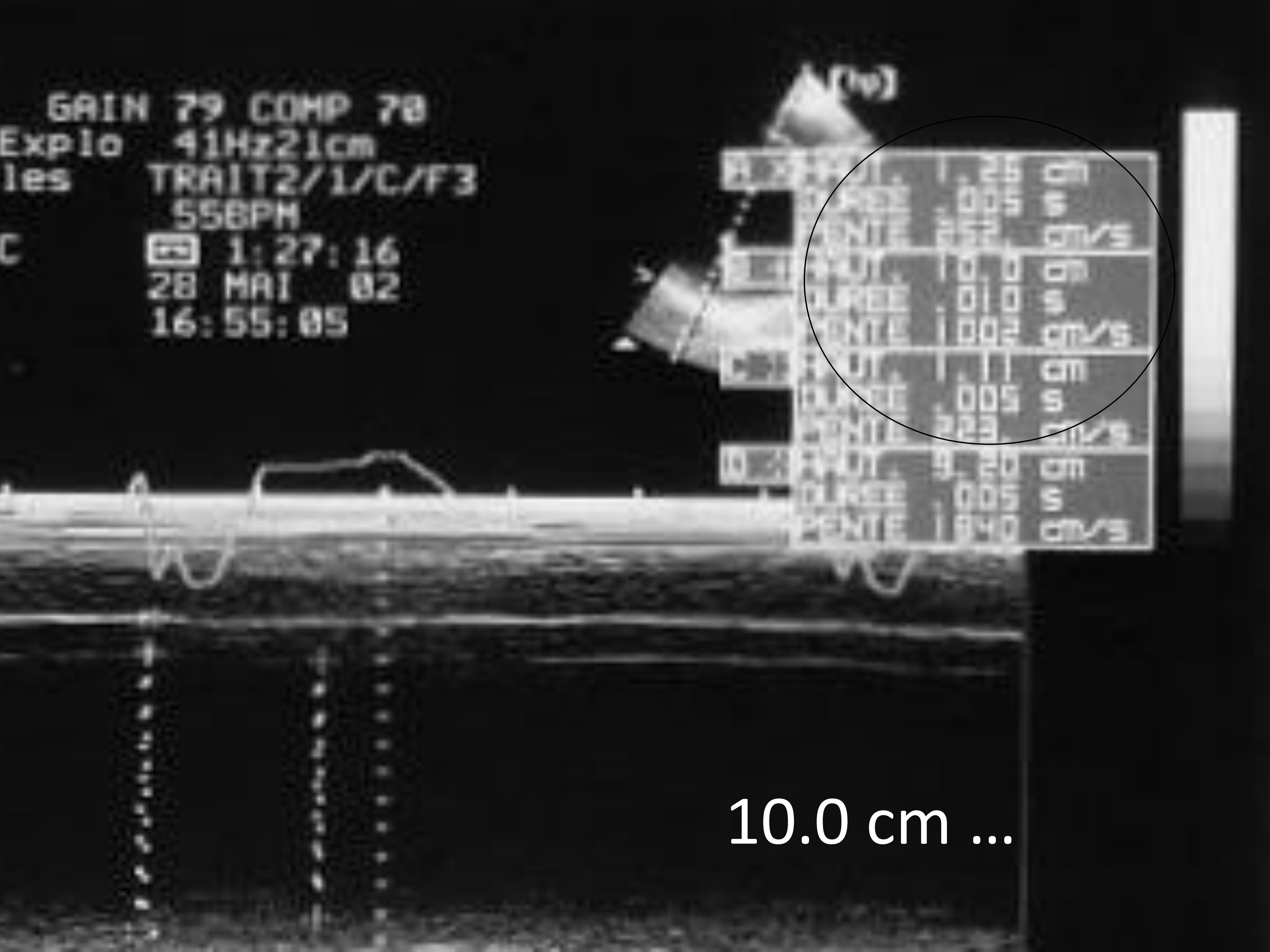
Mesure à 80ms après J (10mm/mV)
Points: Auto

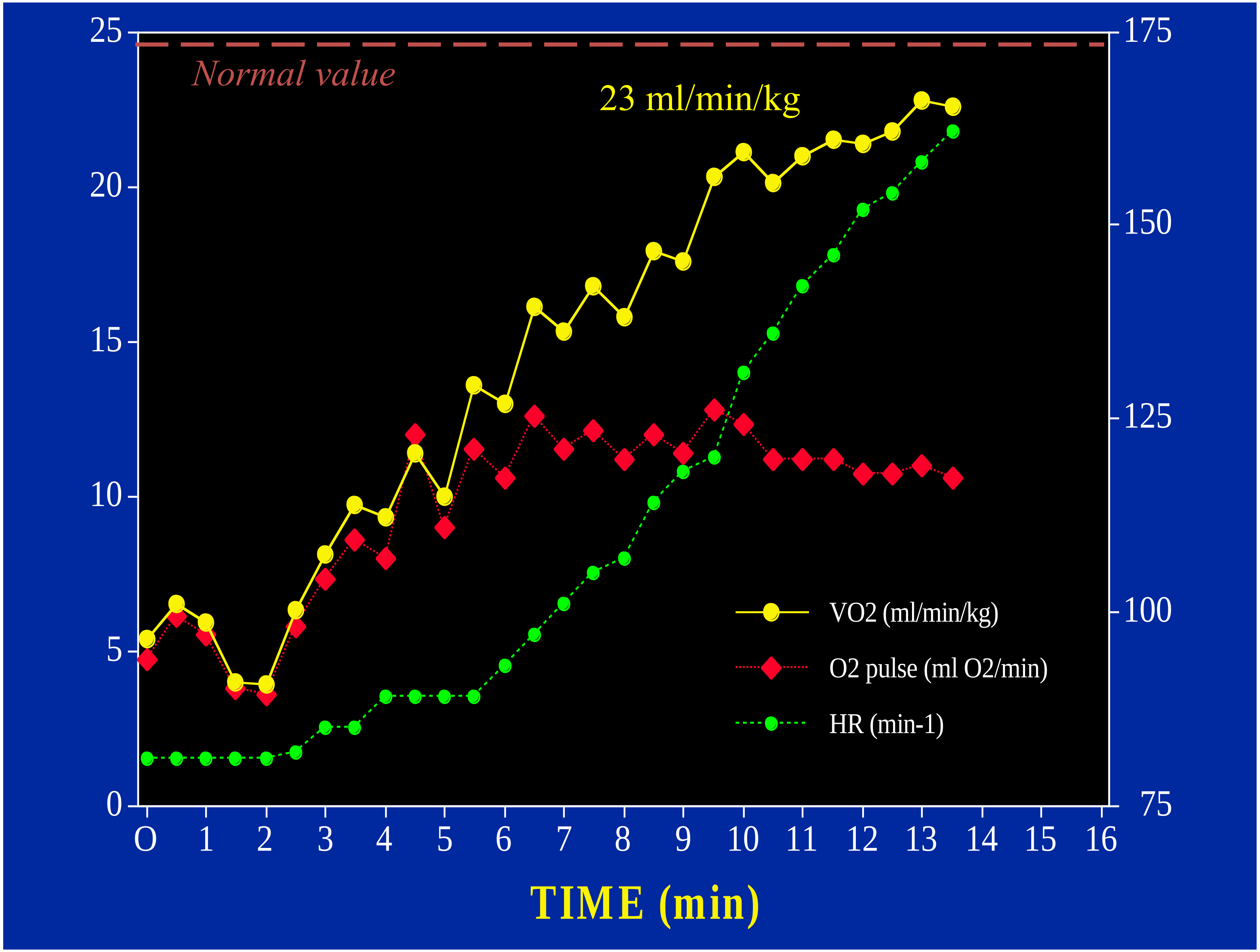
Dériv	ST(mm)	Dériv	ST(mm)
I	-1.2	V1	14.8
II	-2.1	V2	23.3
III	-0.7	V3	22.2
aVR	1.8	V4	10.5
aVL	-0.2	V5	-5.2
aVF	-1.4	V6	-9.2



2 A- M- S+ R+ 50 SFe3 Ffc2 #3868 CASE 006DA

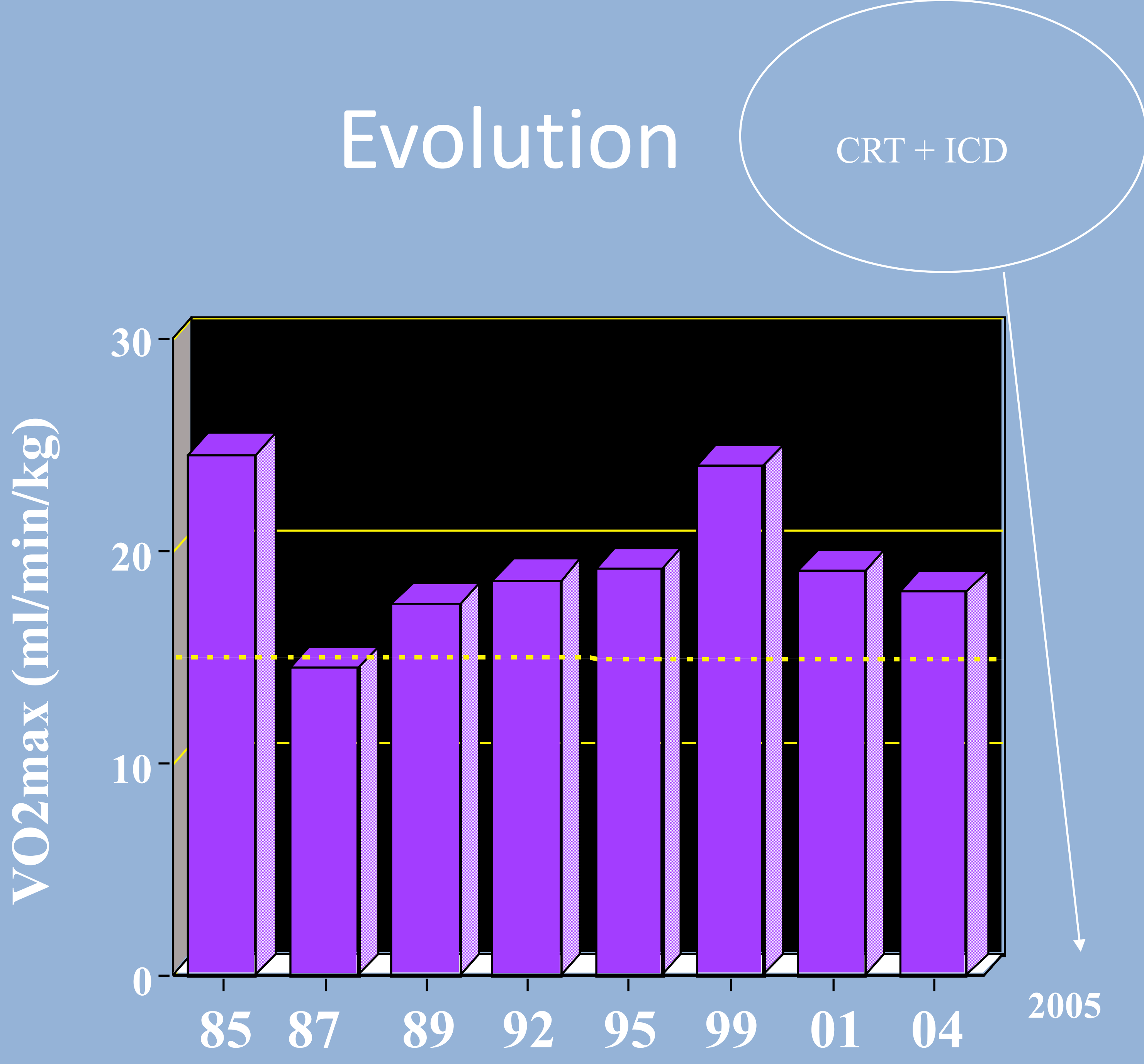

LV
LA


GAIN 79 COMP 70
Explo 41Mz21cm
les TRAIT2/1/C/F3
55BPM
1:27:16
28 MAI 02
16:55:05
HAUT. 1.25 cm
DUREE .005 s
PENTE 252. cm/s
HAUT. 10.0 cm
DUREE .010 s
PENTE 1002 cm/s
HAUT. 1.11 cm
DUREE .005 s
PENTE 223. cm/s
HAUT. 9.20 cm
DUREE .005 s
PENTE 1840 cm/s
10.0 cm ...



Normal value
23 ml/min/kg
VO2 (ml/min/kg)
O2 pulse (ml O2/min)
HR (min-1)
25
20
15
10
5
0
175
150
125
100
75
O
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TIME (min)

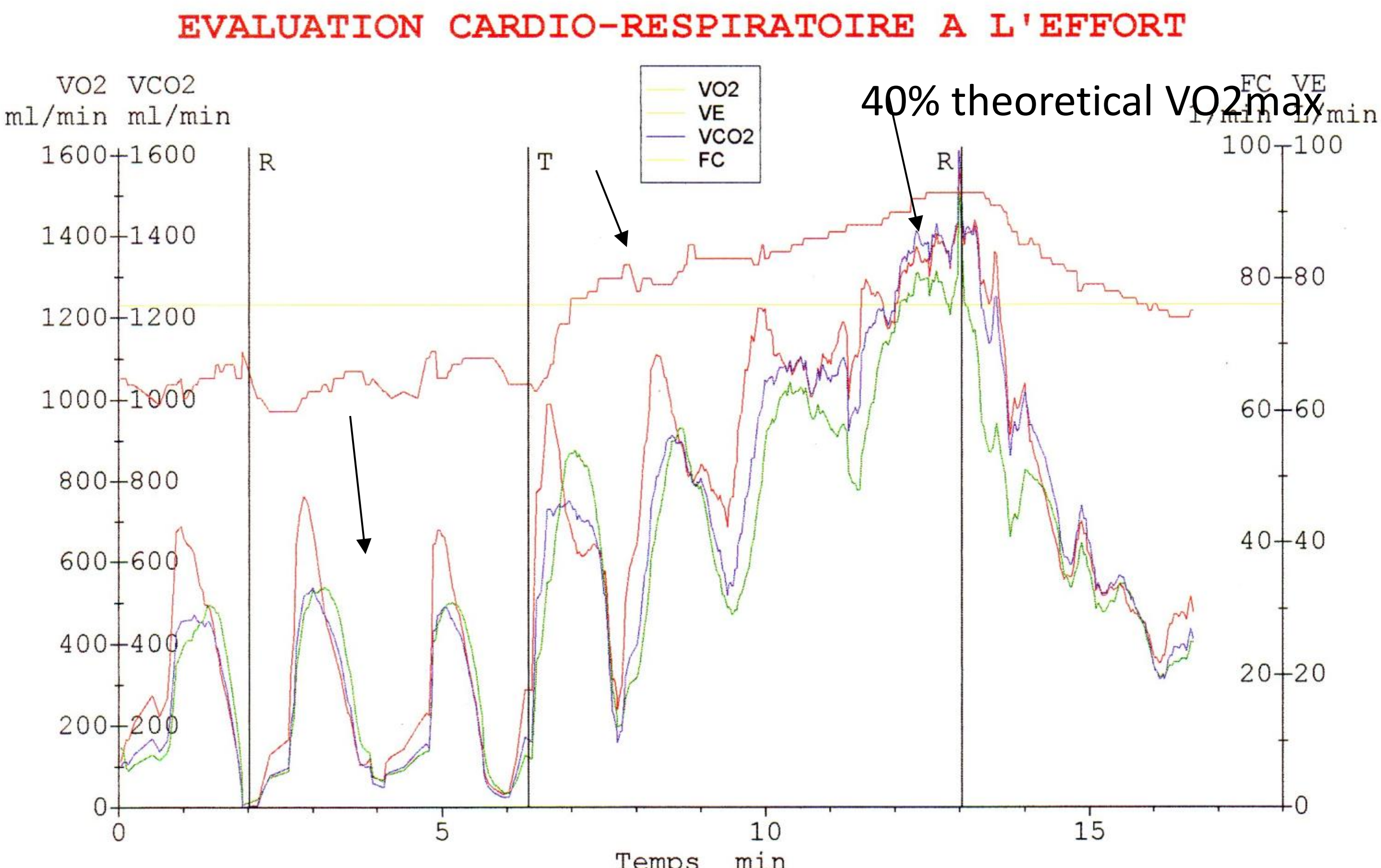
Evolution



Case 3

- Man, 55 y
- Active (peasan)
- CMD (LVEDD 80 mm)
- LVEF 20%
- NYHA III-IV
- Heart transplant?
- But
  - Peak VO2 17 ml/min/kg …
  - Denied HT

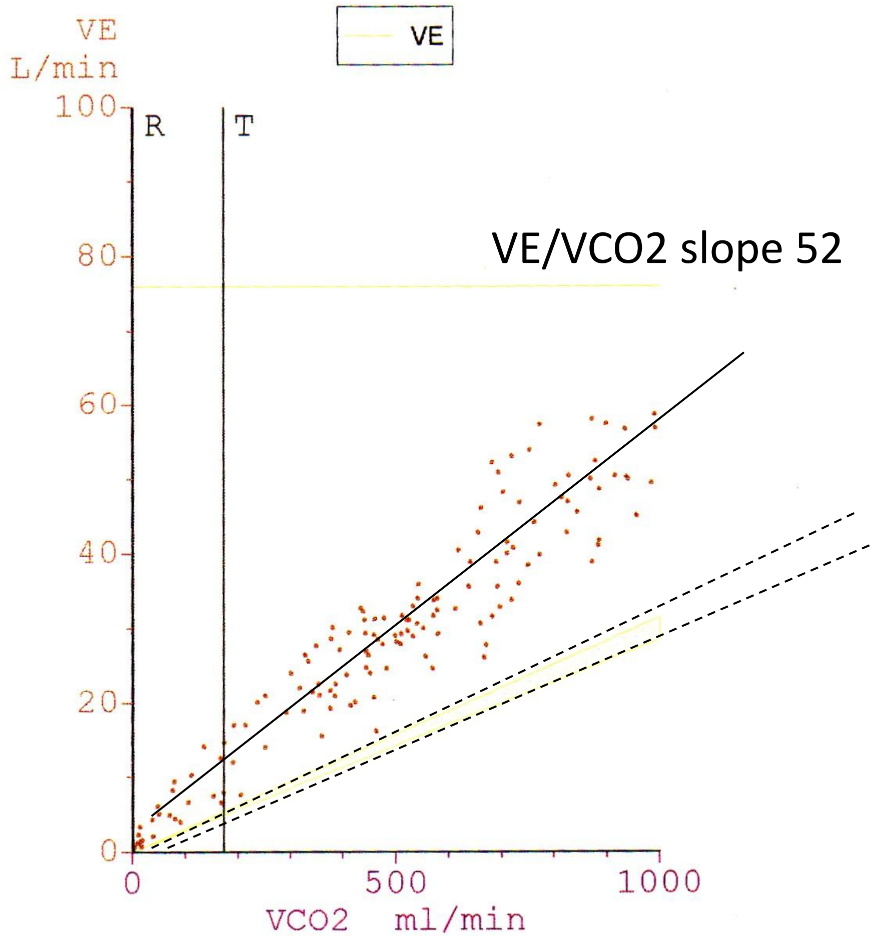
Case 3



BP 90 mm Hg

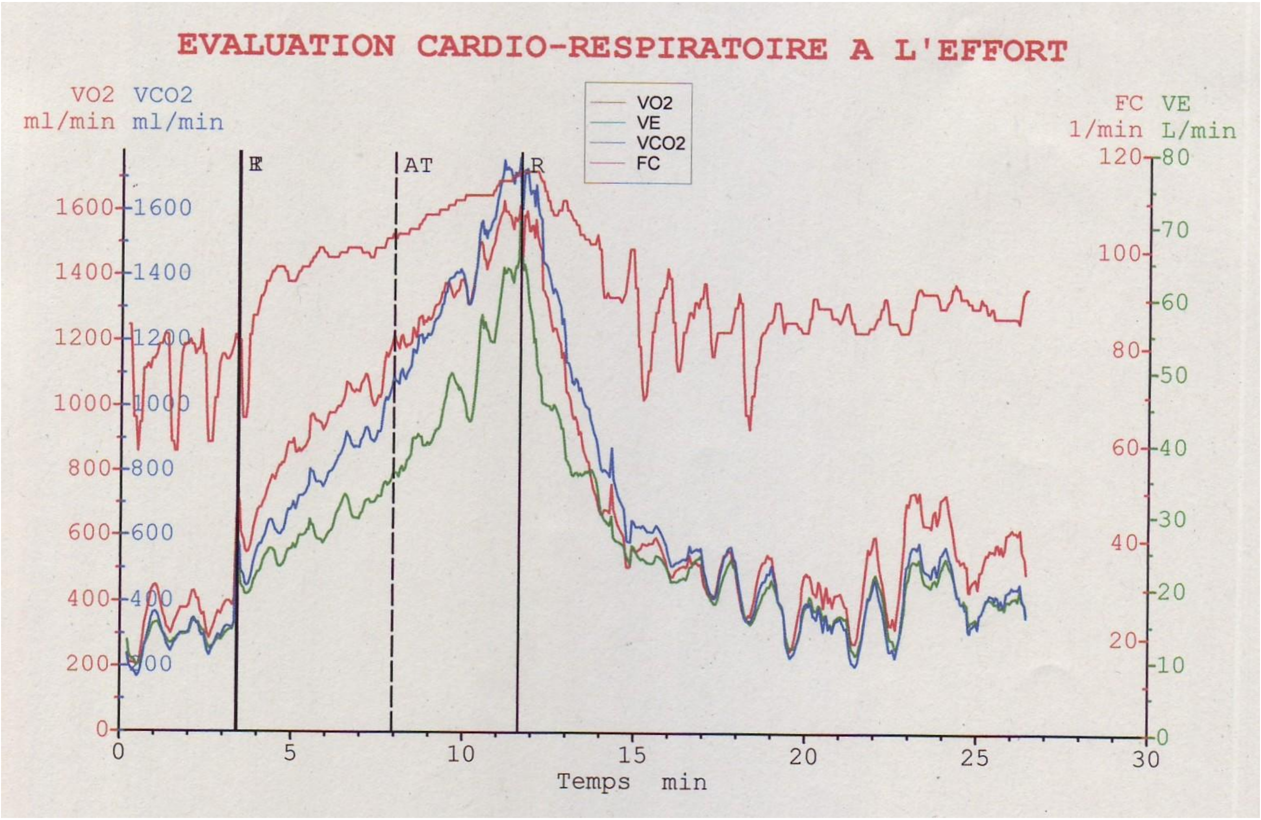
BP100 mm Hg

Case 3

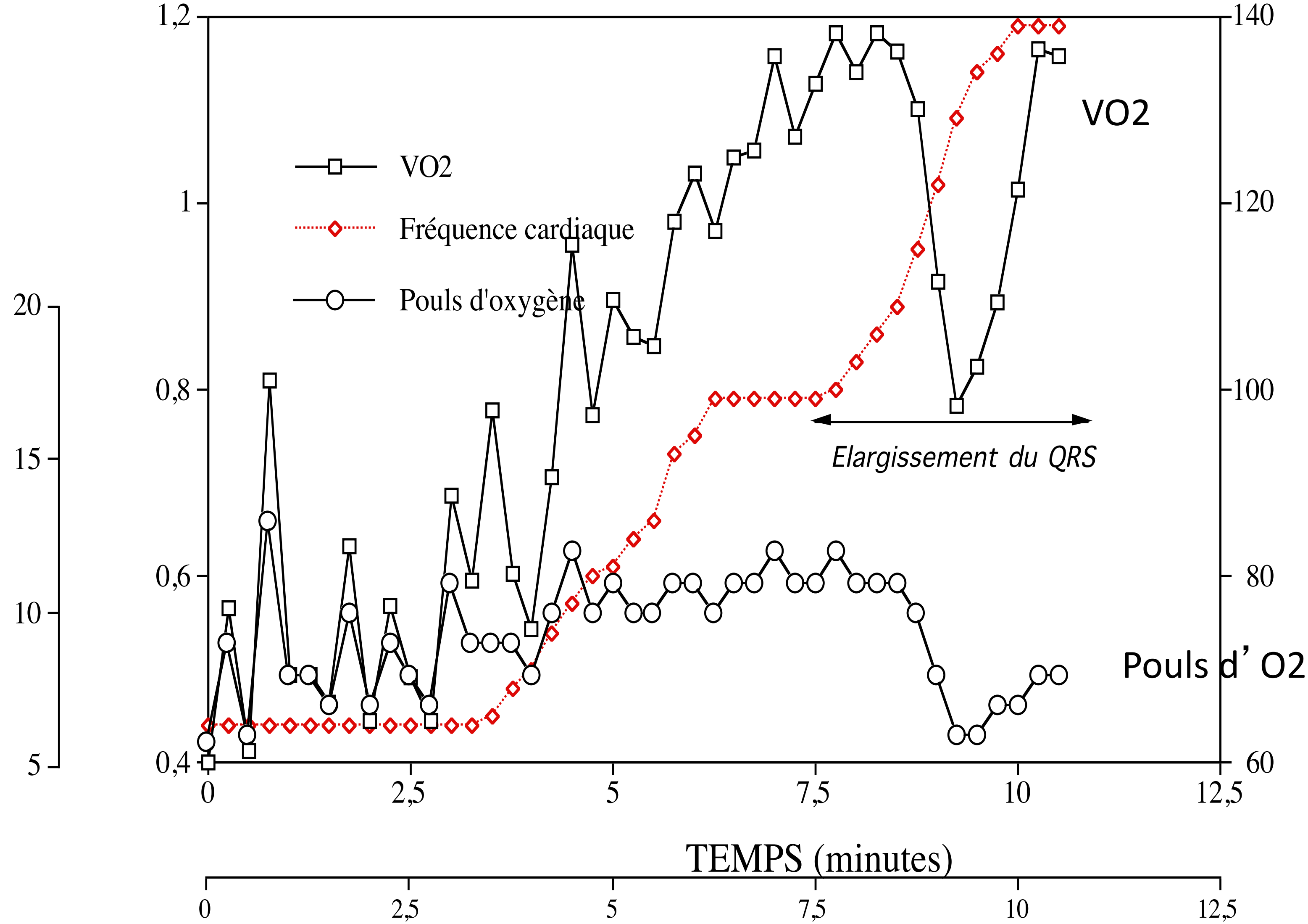


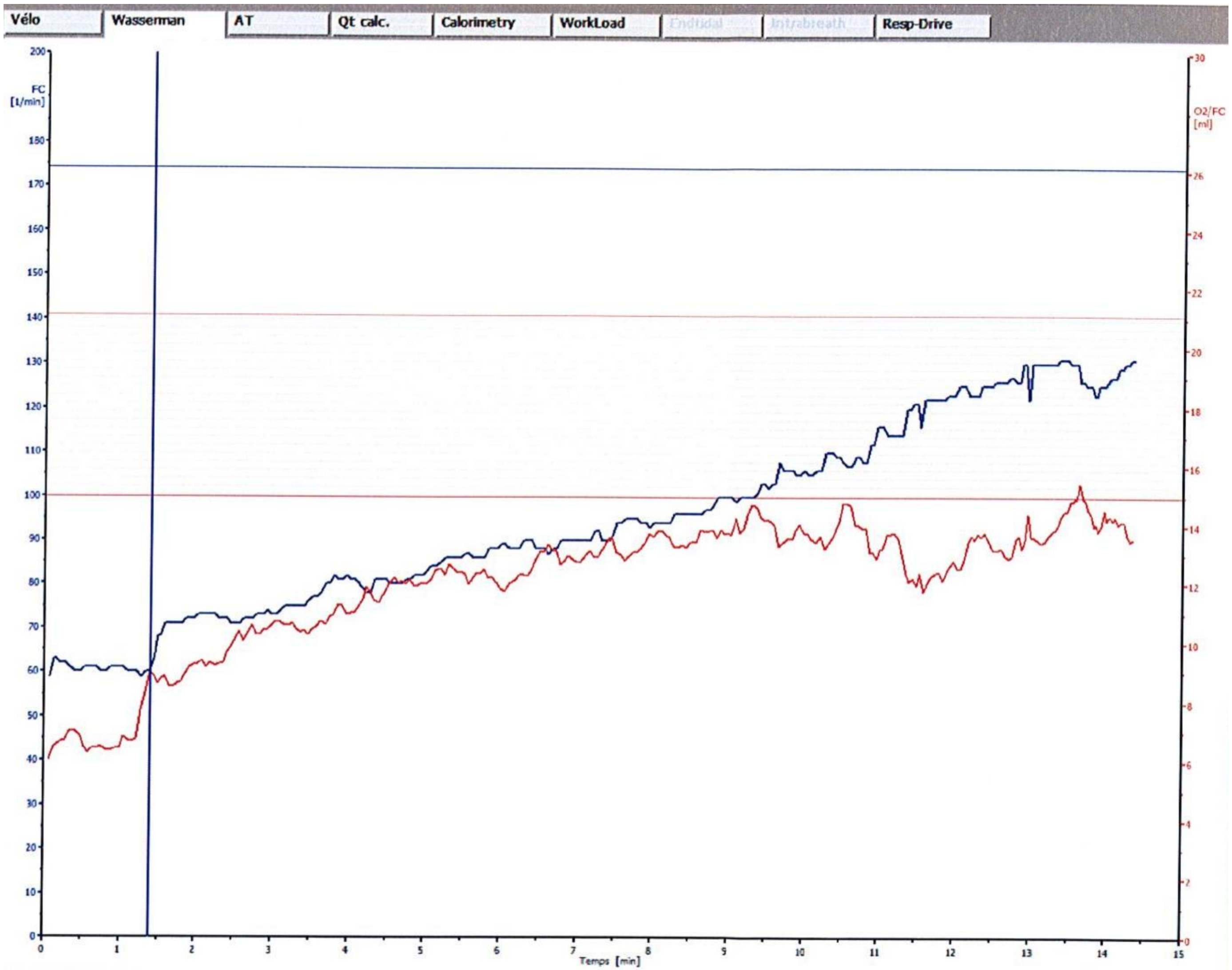
VE
L/min
VE
R
T
VE/VCO2 slope 52
100
80
60
40
20
0
0
500
1000
VCO2 ml/min

CPX with Jarvik 2000 …

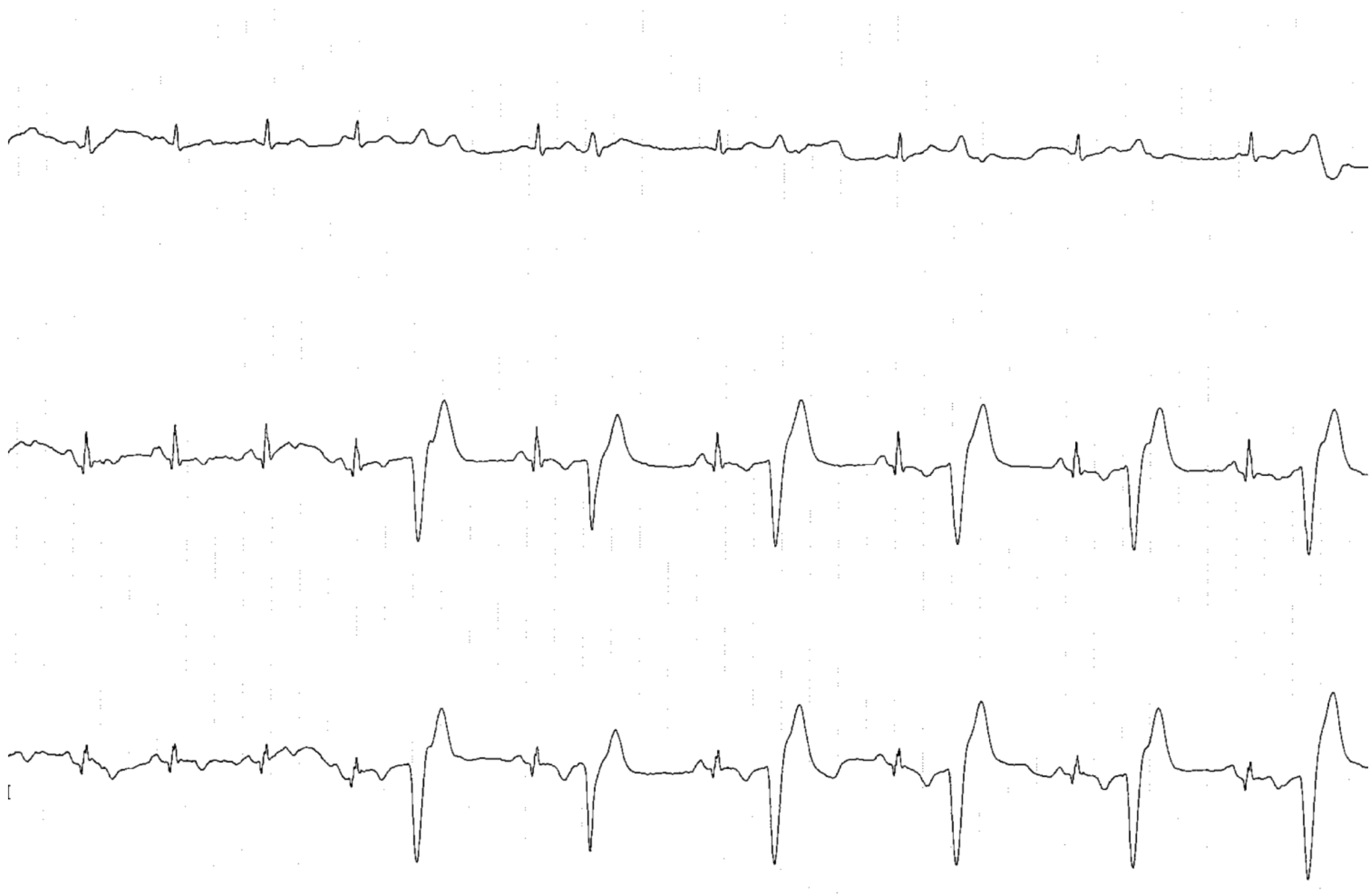


Clinical case : mitral stenosis





Vélo
Wasserman
AT
Qt calc.
Calorimetry
WorkLoad
Endtidal
Intrabreath
Resp-Drive
FC [1/min]
O2/FC [ml]
Temps [min]



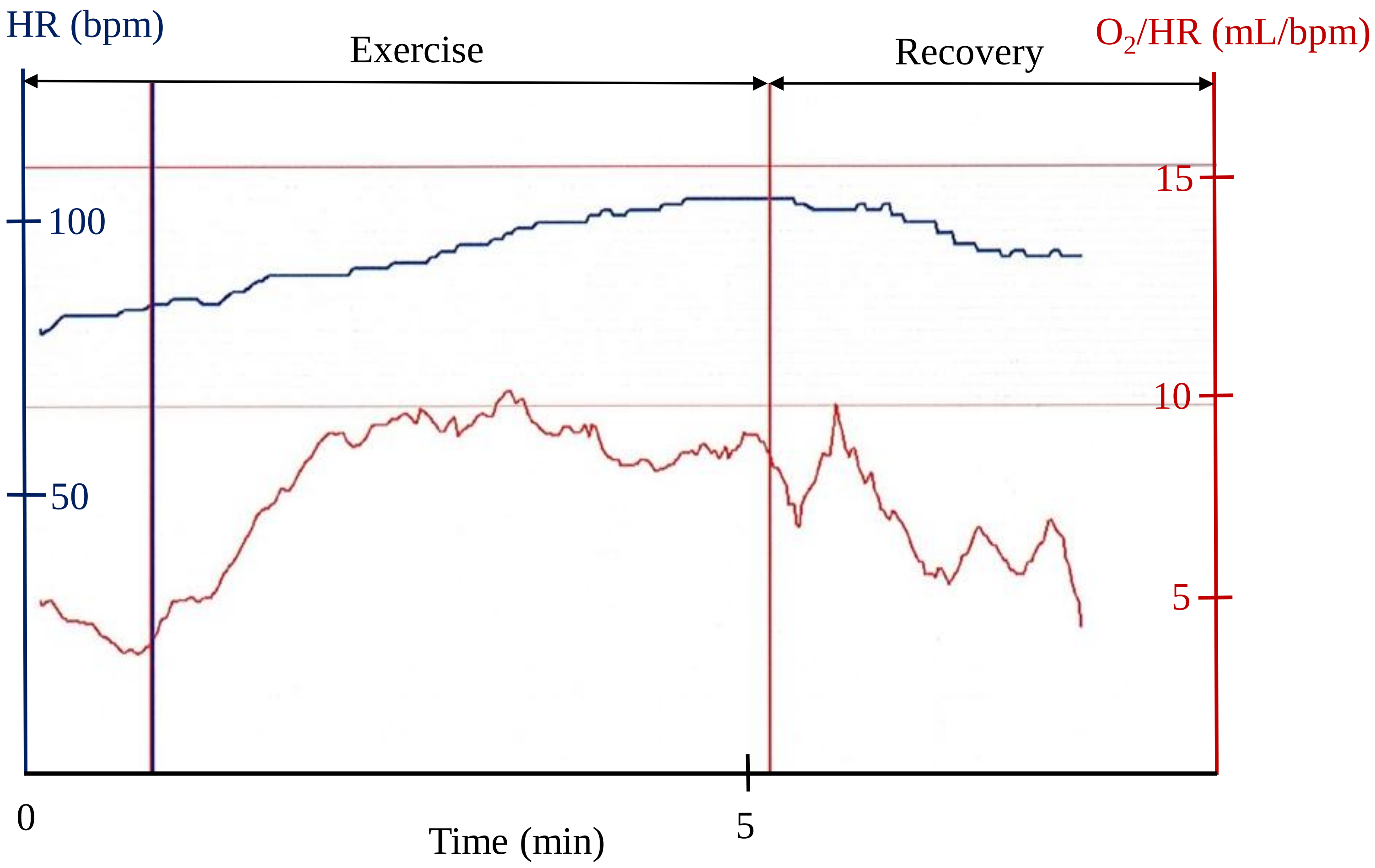


Figure 4. Example of abnormal O2 pulse (in red) and chronotropic incompetence (in blue) in cardiac amyloidosis patients. There is low increase of O2 pulse during exercise : from 4 to 10 mL/bpm (x2,5) and a premature plateauing of O2 pulse.

Conclusion

- CPX reflects the circulatory/pulmonary response during exercise
- CPX should be used in all exercise diagnostic tests (except ischemia detection or BP response)

Practical Guide

Practical Guide to Cardiopulmonary Exercise Testing

Alain Cohen-Solal
François Carré
With the collaboration of Jorge Pinto Ribeiro
Preface from José López-Sendón

ELSEVIER MASSON

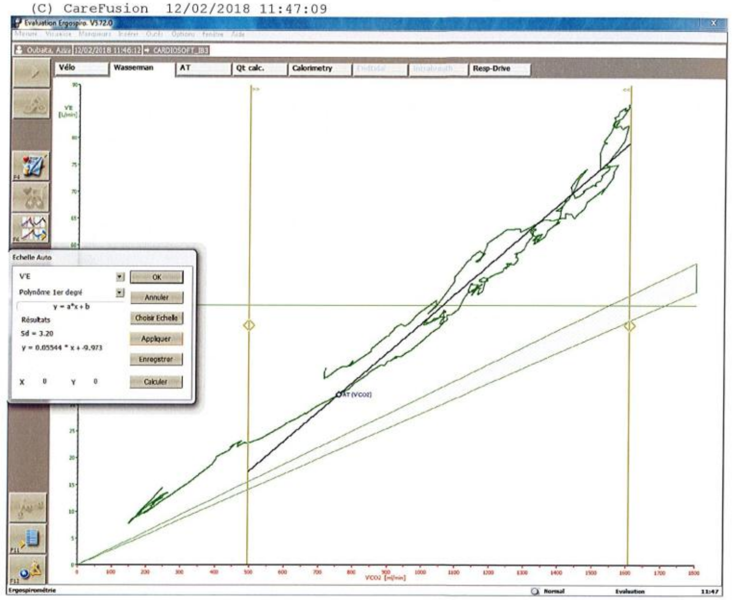
MEDIGUIDES

HOPITAL LARIBOISIERE
Explorations Fonctionnelles cardiologiques Professeur KUBIS
Epreuve d'Effort Cardiorespiratoire

sml_JlabShort.xml
MasterScreen CPX,823142
ON: MSCPx,JDDMSCPX.DeviceManager.1
OxMobileFDR,JDDOXYCONMOBFDR.DeviceManager.1

CD-Version: 5.72.0.61
LAB Core 5.72.0.61 Klinik Informationssys5.72.0.61
Station: X Computer name: CFN823142

(C) CareFusion 12/02/2018 11:47:09



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sml_JlabShort.xml
MasterScreen CPX,823142
ON: MSCPx,JDDMSCPX.DeviceManager.1
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Station: X   Computer name: CFN823142

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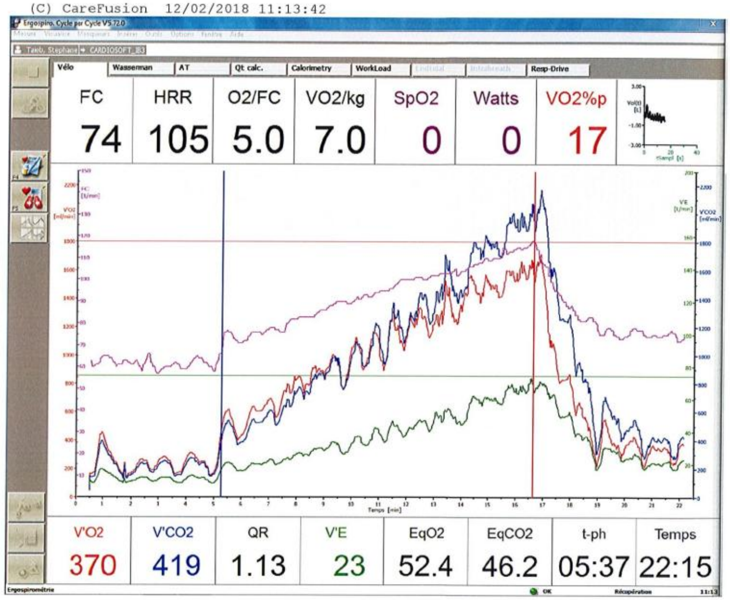

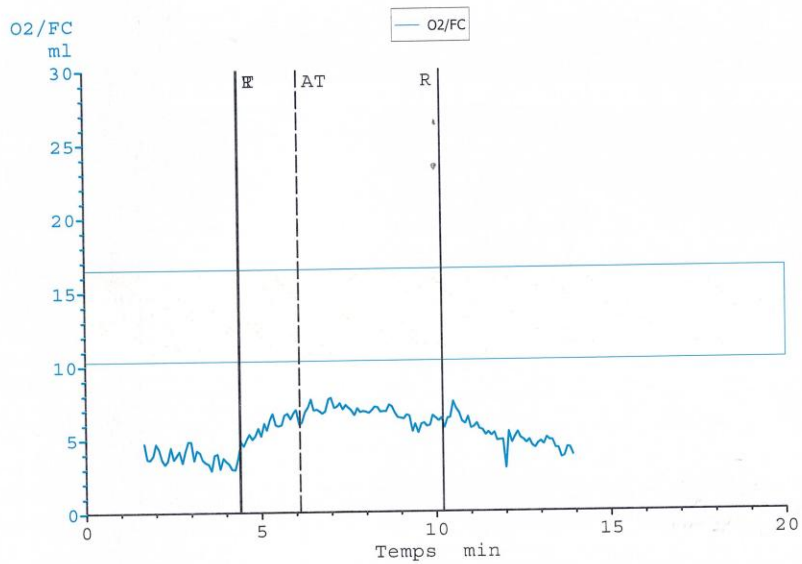

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O2/FC
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20
Temps min