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Rome Cavalieri

Come, quando e perché CPET + emodinamica non invasiva

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Noninvasive Measurement of Cardiac Output During Exercise by Inert Gas Rebreathing Technique: A New Tool for Heart Failure Evaluation

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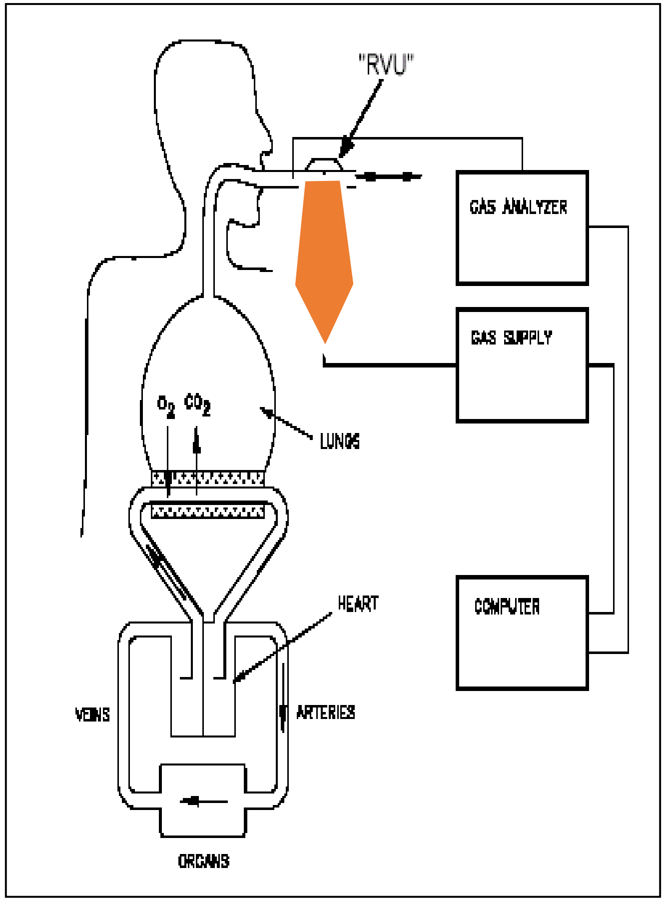
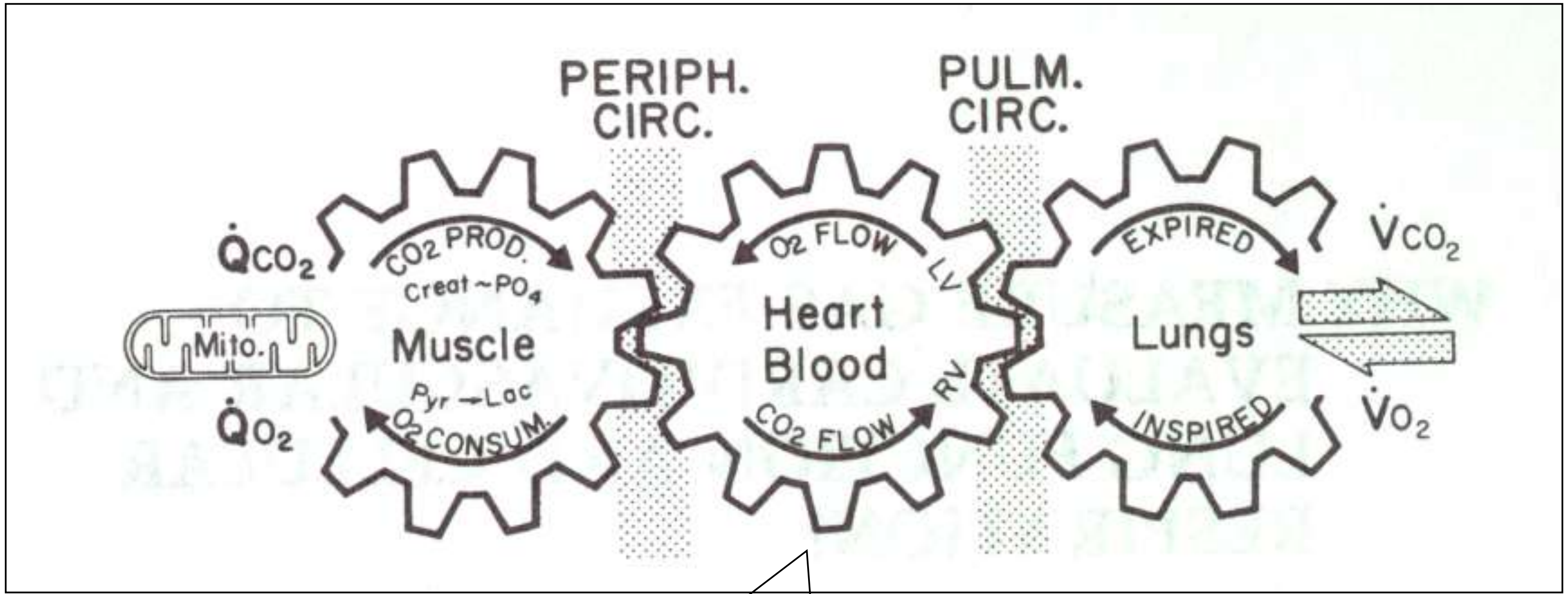
Giancarlo Marenzi, MD
Karlman Wasserman, MD, PhD



- Respirazione in circuito chiuso connessi a un palloncino di gomma pre-riempito con miscela arricchita di ossigeno con due gas estranei
    - gas insolubile esafluoruro di zolfo (SF6) nel sangue
    - gas solubile ossido nitroso (N2O) nel sangue.
- Switch automatico di connessione verso aria ambiente alla fine del test
- Misurazione continua on-line dei gas con analizzatore fotoacustico alla bocca (più veloce e stabile di uno spettrometro di massa)

VO_2

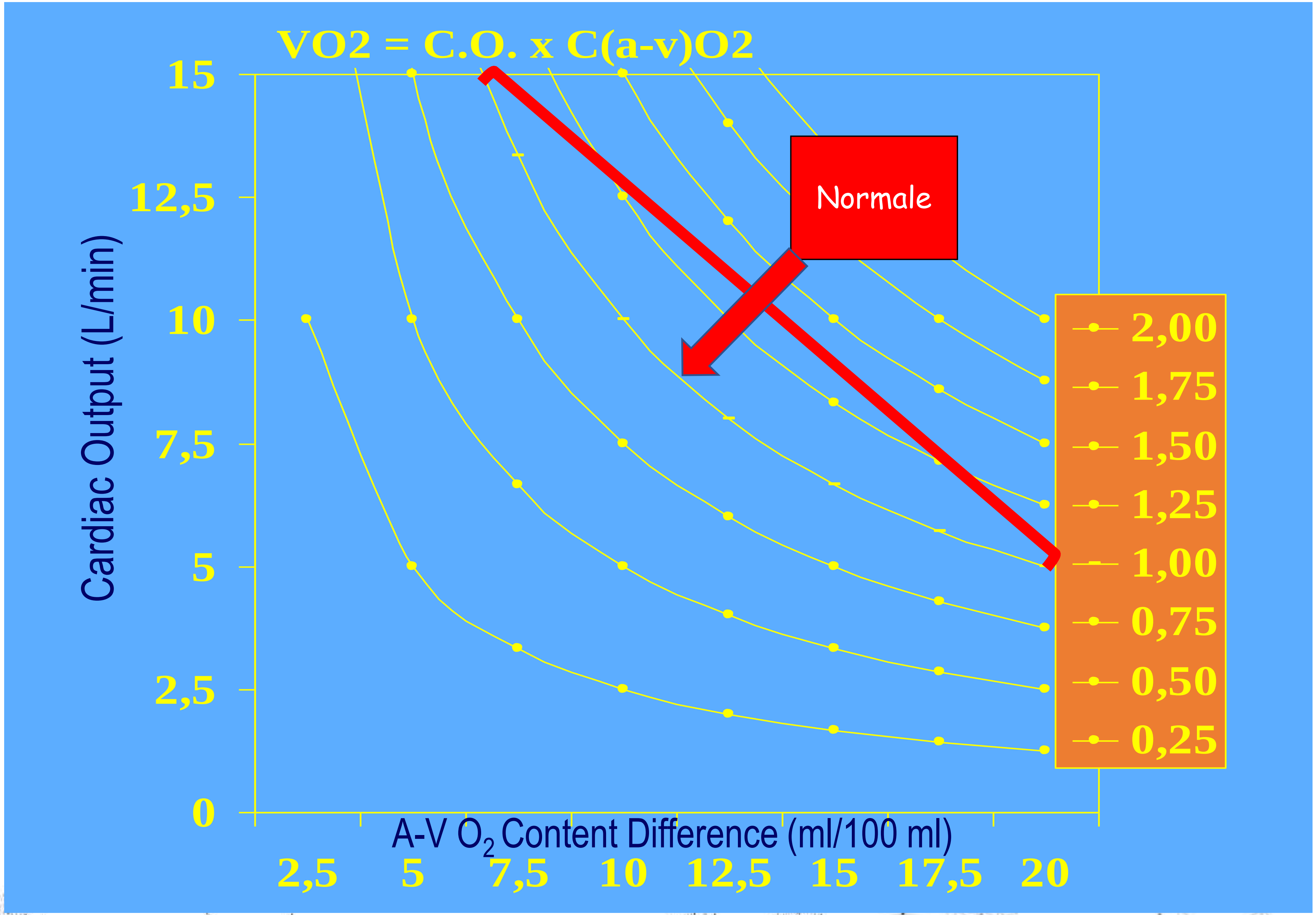


Cardiac Output

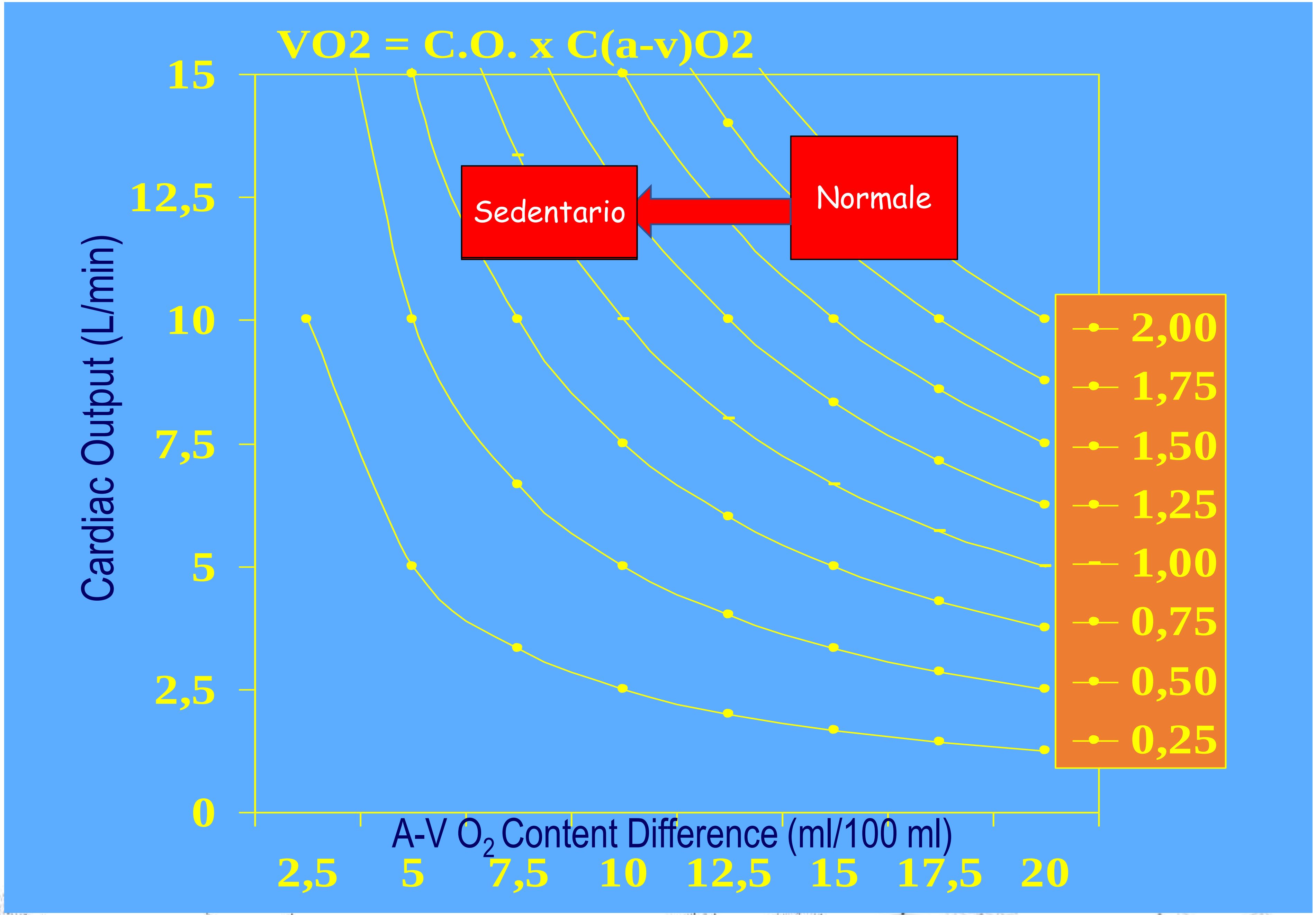
Legge di Fick

VO_2

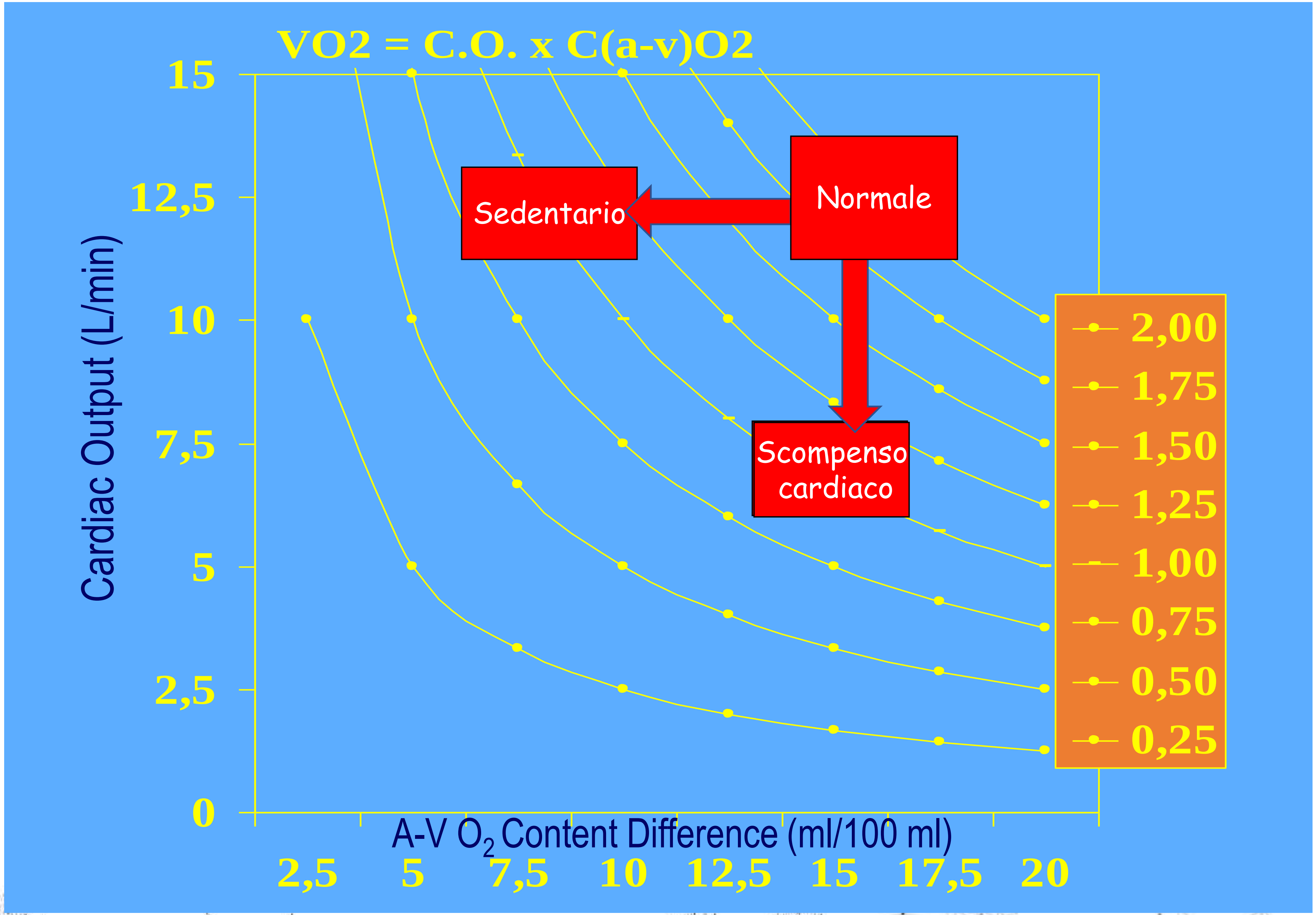
CO X $C(a\text{-}v)O_2$



VO2 = C.O. x C(a-v)O2
Normale
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
A-V O_2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25



VO2 = C.O. x C(a-v)O2
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
Sedentario
Normale
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25
A-V O2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20



VO2 = C.O. x C(a-v)O2
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
A-V O_2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20
Sedentario
Normale
Scompenso cardiaco
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25

Legge di Fick

VO_2

CO

- Gettata sistolica
- Frequenza cardiaca

X

$C(a-v)O_2$

- Hb
- SatHb O_2
- pO_2

Legge di Fick

VO_2

CO X $C(a\text{-}v)O_2$

CO:
- Gettata sistolica
- Frequenza cardiaca

$C(a\text{-}v)O_2$:
- **Hb**
- SatHb O_2
- pO_2

Quanto conta l'anemia?

1 gr di Hb porta ai tessuti 1 ml O_2 x dl di sangue

Quanto conta l'anemia?

1 gr di Hb porta ai tessuti 1 ml O_2 x dl di sangue

Se Cardiac Output al picco Ex = 10 L/'

Anemia 5 gr/dl

Quanto conta l'anemia?

1 gr di Hb porta ai tessuti 1 ml O_2 x dl di sangue

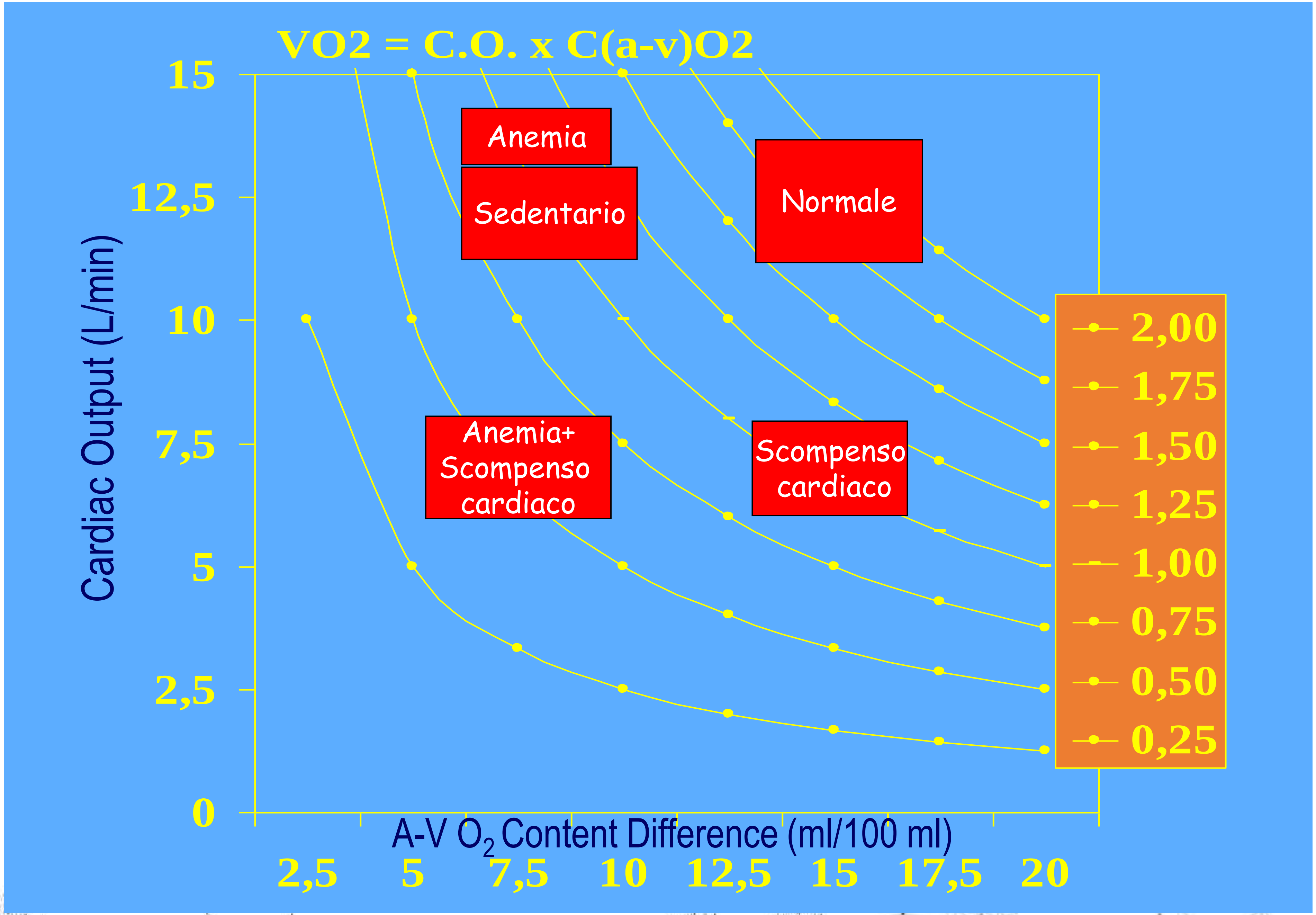
Se Cardiac Output al picco Ex = 10 L/'

Anemia 5 gr/dl

VO_2Max ridotto di

5x100 =500 ml/'

solo per anemia



VO2 = C.O. x C(a-v)O2
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
Anemia
Sedentario
Normale
Anemia+ Scompenso cardiaco
Scompenso cardiaco
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25
A-V O2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20

Teoria

Teoria → Applicazione clinica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a\text{-}v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

1040 ml/min

74% → 920 ml/min

26% → 120 ml/min

Hb 13.5 gr/dl

Hb: 119 ml/min

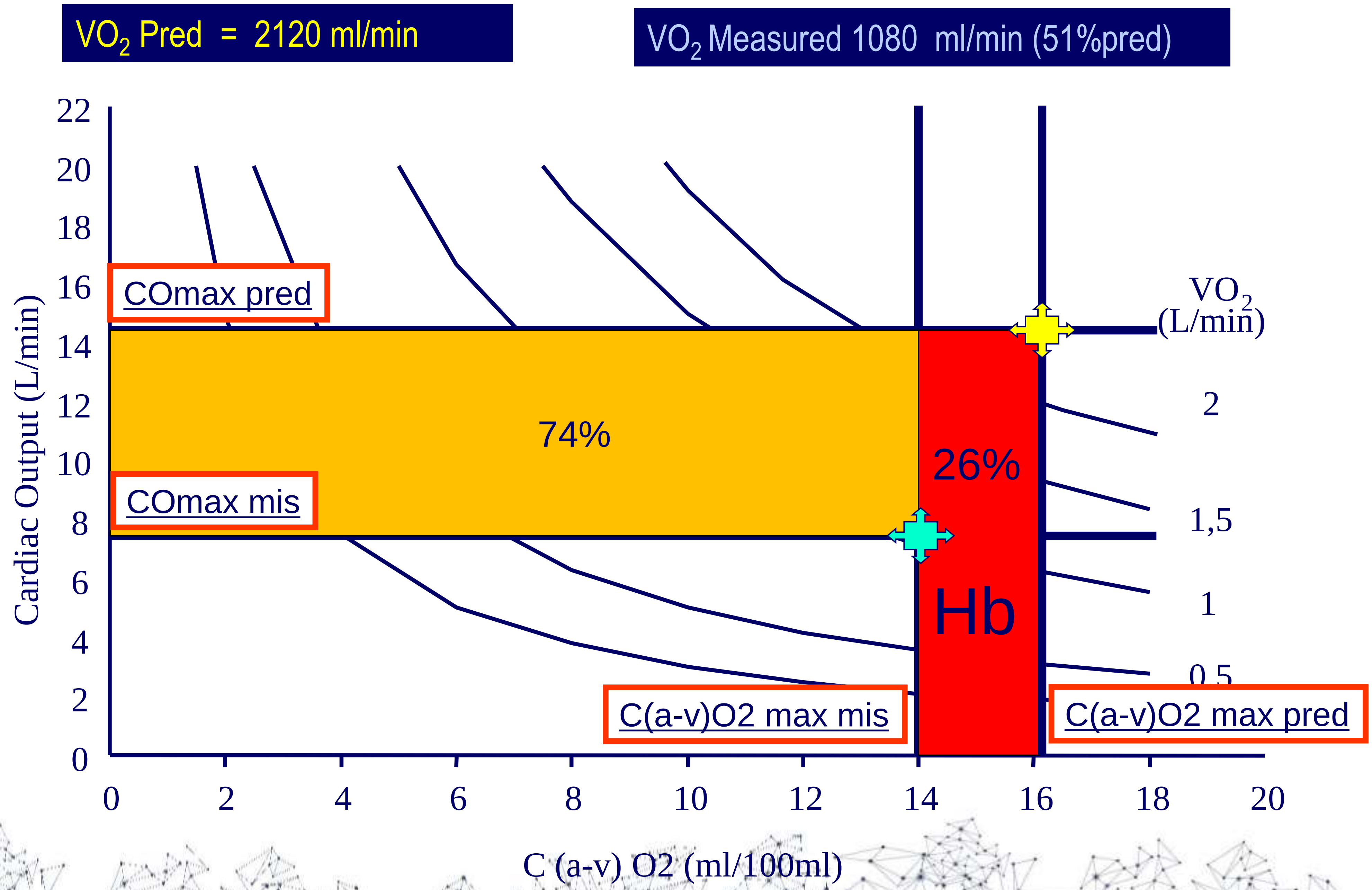
46% (HR) – 54% (SV)

<u>CONCLUSIONI:</u>

Severa riduzione della capacità funzionale (VO_2 max 51% del predetto).

Limitazione all'esercizio dovuta a:

- anemia (26%)
- limitazione cardiogenica (74%) legata a incompetenza cronotropa (46%) e deficit sistolico (54%).



VO2 Pred = 2120 ml/min
VO2 Measured 1080 ml/min (51%pred)
Cardiac Output (L/min)
22
20
18
16
14
12
10
8
6
4
2
0
COmax pred
COmax mis
74%
26%
Hb
VO2 (L/min)
2
1,5
1
0,5
C(a-v)O2 max mis
C(a-v)O2 max pred
0
2
4
6
8
10
12
14
16
18
20
C (a-v) O2 (ml/100ml)

Come, quando e perché
CPET + emodinamica non invasiva

Limitazione Funzionale

Limitazione Cardiogenica
- Gettata Sistolica
- Incompetenza cronotropa

Limitazione “Periferica”
- Anemia

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Use of Cardiopulmonary Exercise Testing With Hemodynamic Monitoring in the Prognostic Assessment of Ambulatory Patients With Chronic Heart Failure

Marco Metra, MD,* Pompilio Faggiano, MD,† Antonio D'Aloia, MD,* Savina Nodari, MD,* Anna Gualeni, MD,* Domenica Raccagni, MD,* Livio Dei Cas, MD*

Brescia, Italy

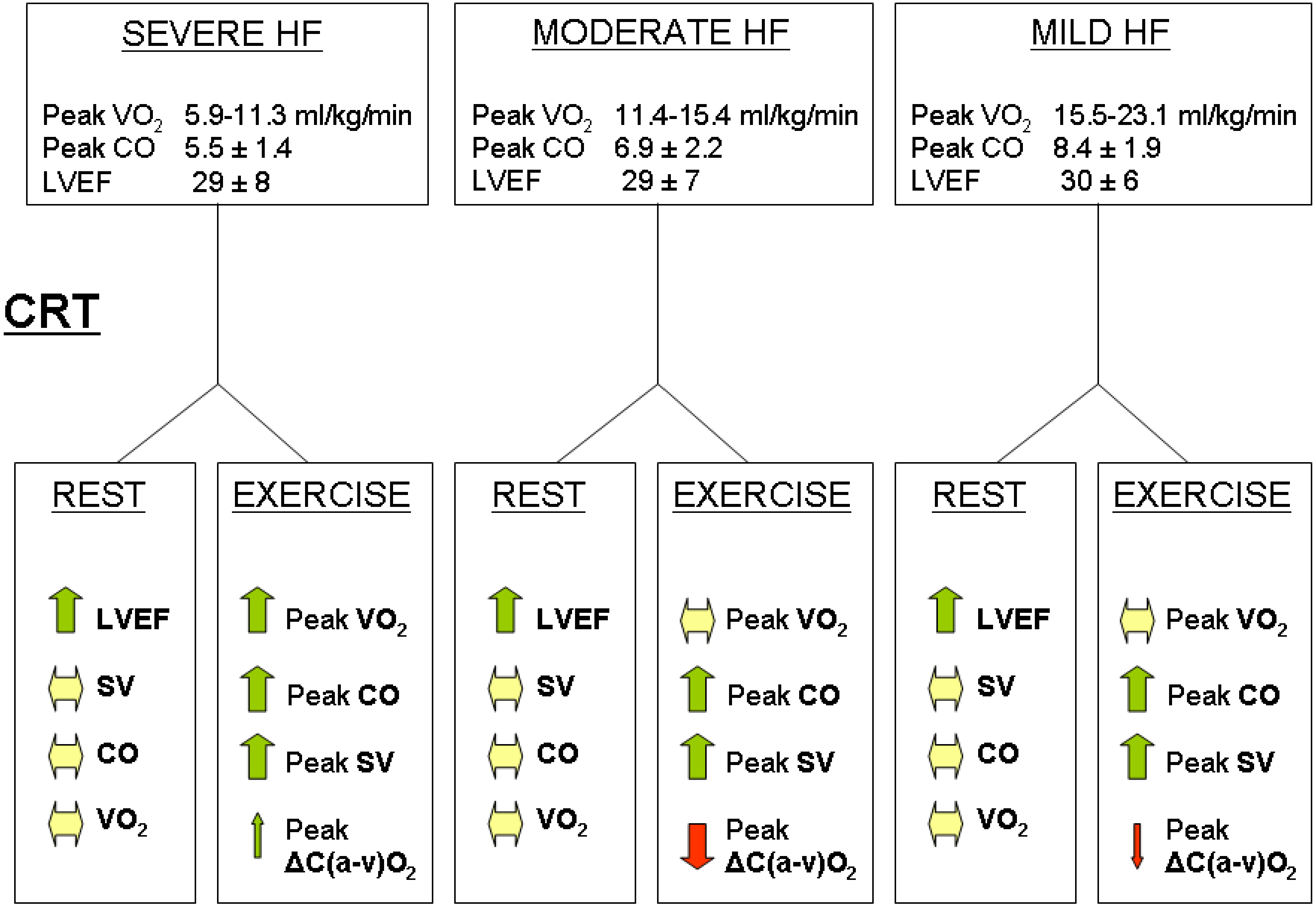
OBJECTIVES We studied whether direct assessment of the hemodynamic response to exercise could improve the prognostic evaluation of patients with heart failure (HF) and identify those in whom the main cause of the reduced functional capacity is related to extracardiac factors.

BACKGROUND Peak exercise oxygen consumption (VO_2) is one of the main prognostic variables in patients with HF, but it is influenced also by many extracardiac factors.

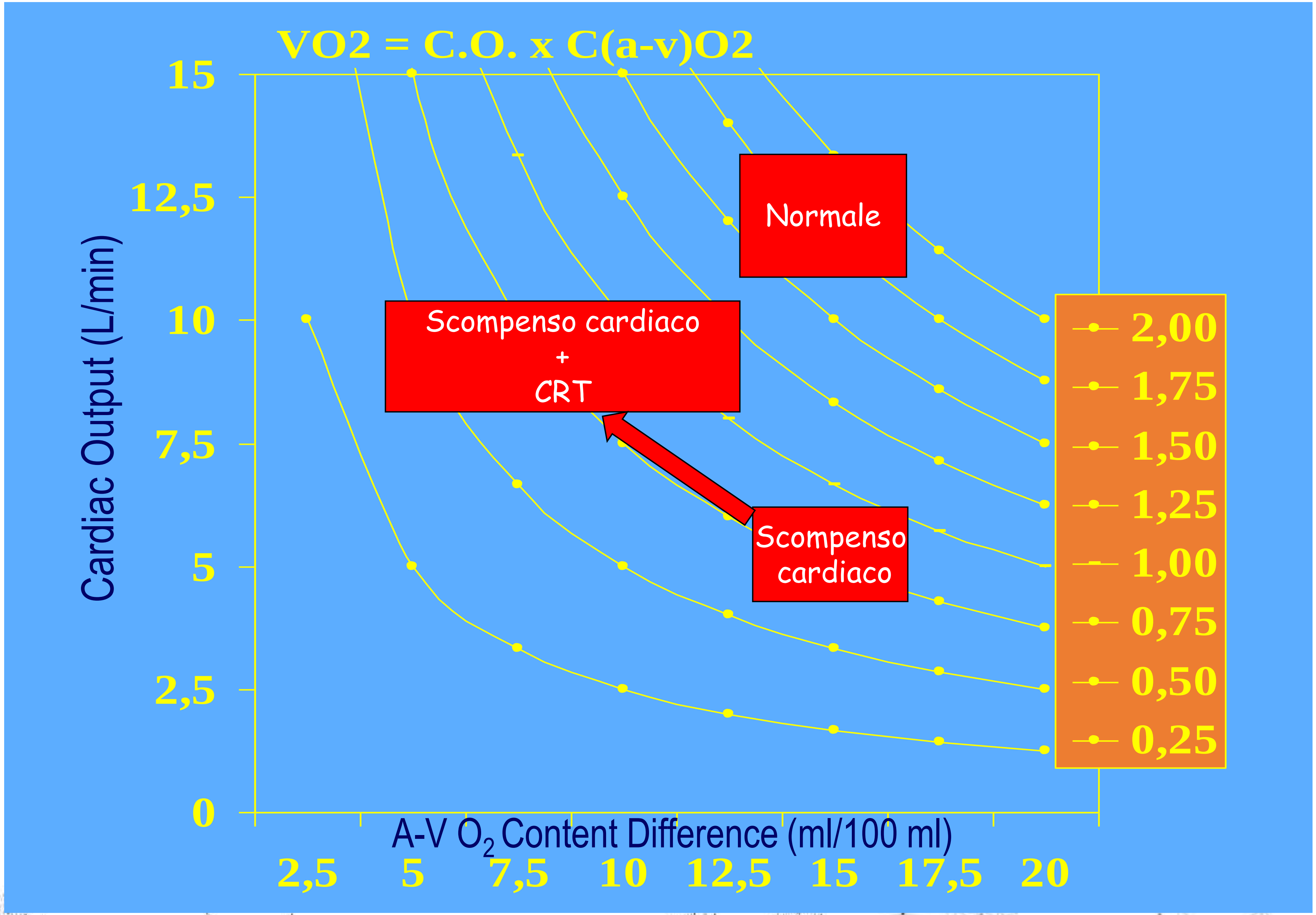
METHODS Bicycle cardiopulmonary exercise testing with hemodynamic monitoring was performed, in addition to clinical evaluation and radionuclide ventriculography, in 219 consecutive patients with chronic HF (left ventricular ejection fraction, 22 ± 7%; peak VO_2, 14.2 ± 4.4 ml/kg/min).

RESULTS During a follow-up of 19 ± 25 months, 32 patients died and 6 underwent urgent transplantation with a 71% cumulative major event-free 2-year survival. Peak exercise stroke work index (SWI) was the most powerful prognostic variable selected by Cox multivariate analysis, followed by serum sodium and left ventricular ejection fraction, for one-year survival, and peak VO_2 and serum sodium for two-year survival. Two-year survival was 54% in the patients with peak exercise SWI ≤30 g·m/m^2 versus 91% in those with a SWI >30 g·m/m^2 ($p < 0.0001$). A significant percentage of patients (41%) had a normal cardiac output response to exercise with an excellent two-year survival (87% vs. 58% in the others) despite a relatively low peak VO_2 (15.1 ± 4.7 ml/kg/min).

CONCLUSIONS Direct assessment of exercise hemodynamics in patients with HF provides additive independent prognostic information, compared to traditional noninvasive data. (J Am Coll Cardiol 1999;33:943–50) © 1999 by the American College of Cardiology



Cattadori G, Viganti C, Bonomi A, Mapelli M, Sciomer S, Pepi M, Tondo C, Ambrosio G, Di Marco S, Baravelli M, Agostoni PG. *Cardiol Cardiovasc Med 2020; 4 (4): 386-95*


VO2 = C.O. x C(a-v)O2
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
A-V O_2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20
Normale
Scompenso cardiaco
+
CRT
Scompenso cardiaco
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25

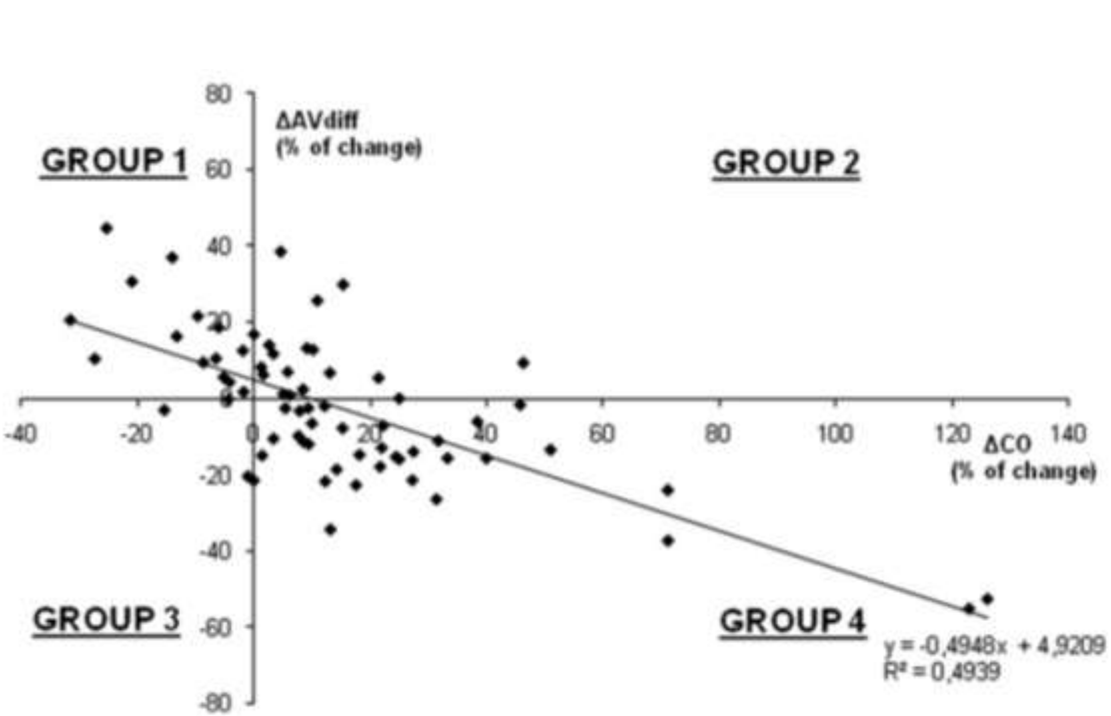
Hemodynamic Effects of Exercise Training in Heart Failure

GAIA CATTADORI, MD,[1] JEAN-PAUL SCHMID, MD,[2] NICOLAS BRUGGER, MD,[2] ERICA GONDONI, MD,[1]
PIETRO PALERMO, MD,[1] AND PIERGIUSEPPE AGOSTONI, MD, PhD[1,3,4]

Milan, Italy; Bern, Switzerland; and Seattle, Washington

ABSTRACT

Background: Exercise performance improvement after training in heart failure (HF) can be due to central or peripheral changes.
Methods and Results: In 70 HF stable patients we measured peak VO_2 and cardiac output (CO, inert gas rebreathing technique) and calculated arteriovenous O_2 differences (a-v O_2diff) before and after an 8-week training program. Peak VO_2 changed from 1111 ± 403 mL/minute to 1191 ± 441 (*P* < .001), peak workload from 68 ± 29 watts to 76 ± 32 (*P* < .0001), peakCO from 6.6 ± 2.2 L/minute to 7.3 ± 2.5 (*P* < .0001), and peak a-v O_2diff from 17.5 ± 5.1 mL/100 mL to 16.6 ± 4.1 (*P* = .081). Changes in peak CO and a-v O_2diff allowed to identify 4 behaviors: group 1: (n = 15) reduction in peak CO and increase in a-v O_2diff (peak VO_2 unchanged, peak workload +9.5%); group 2: (n = 16) both peak CO and a-v O_2diff increased as well as peak VO_2 (23%) and workload (18%); group 3: (n = 4) peak CO and a-v O_2diff reduced as well as peak VO_2 (-18%) and workload (-5%); group 4: (n = 35) peak CO increased with a-v O_2diff reduced (increase in peak VO_2 by 5.5 and workload by 8.4%).
Conclusions: Exercise training improves peakVO_2 by increasing CO with unchanged a-v O_2diff. A reduction after training of a-v O_2diff with an increase in CO is frequent (50% of cases), is suggestive of blood flow redistribution and, per se, not a sign of reduced muscle performance been associated with improved exercise capacity. (*J Cardiac Fail 2011;17:916–922*)
Key Words: Training, heart failure, cardiac output.



ESC HEART FAILURE

ORIGINAL ARTICLE

ESC Heart Failure 2021; **8**: 4915–4924

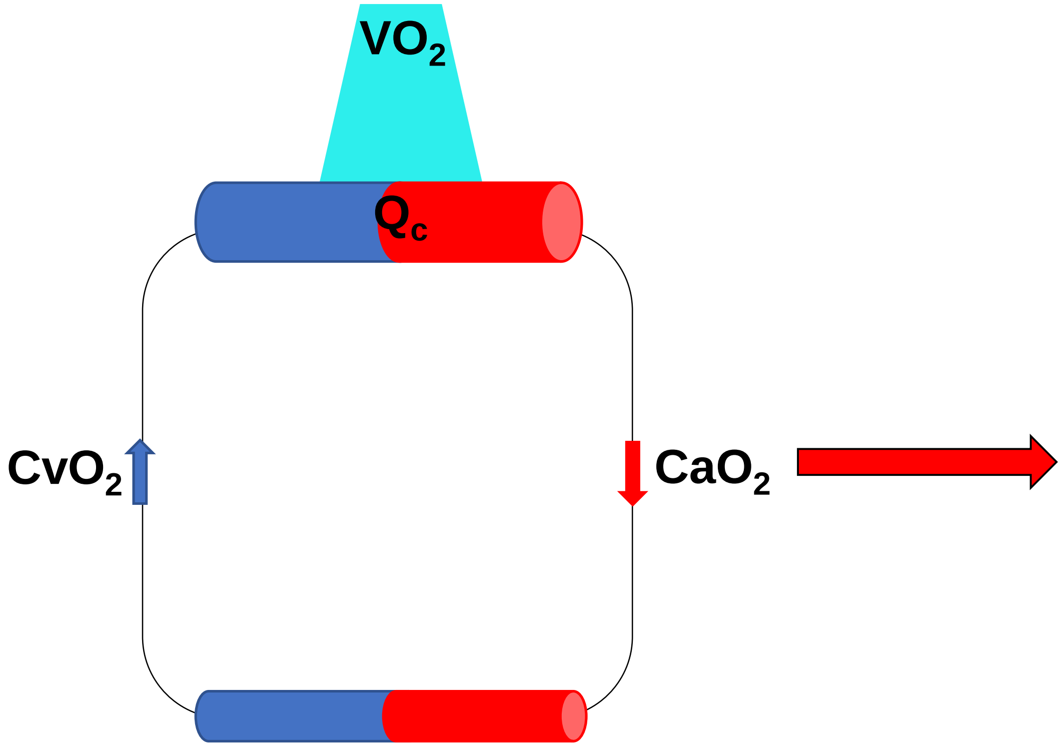
Published online 22 September 2021 in Wiley Online Library (wileyonlinelibrary.com) **DOI:** 10.1002/ehf2.13518

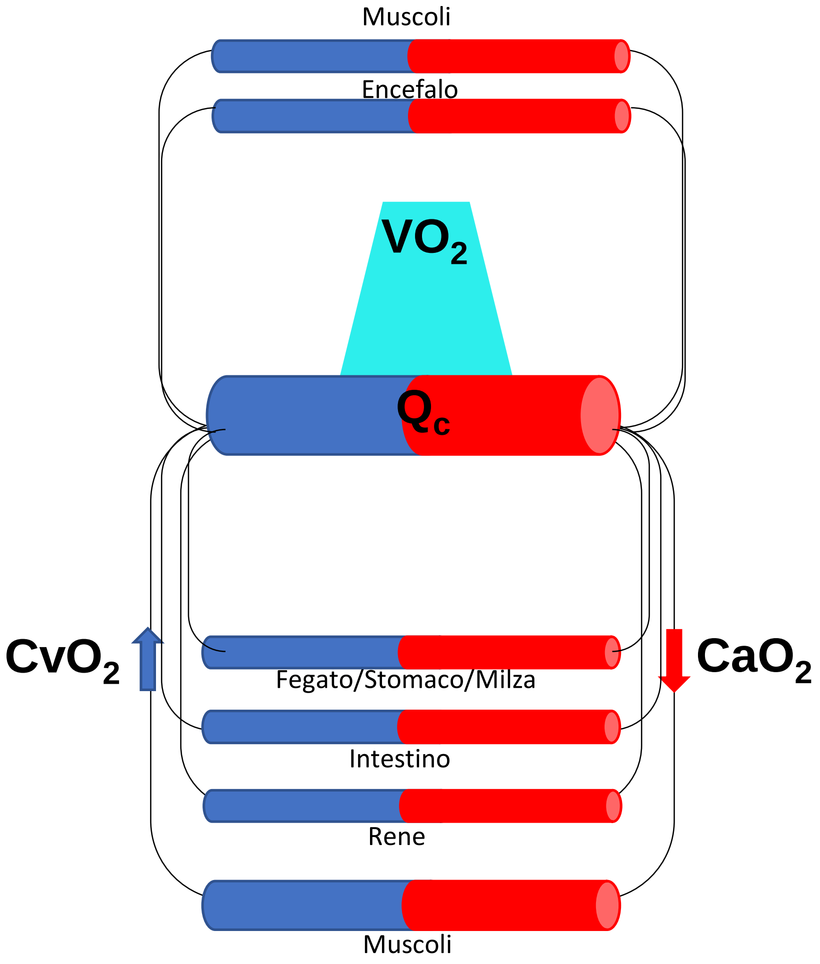
Rest and exercise oxygen uptake and cardiac output changes 6 months after successful transcatheter mitral valve repair

Carlo Vignati[1,2], Fabiana De Martino[1], Manuela Muratori[1], Elisabetta Salvioni[1], Gloria Tamborini[1], Antonio Bartorelli[1,3], Mauro Pepi[1], Francesco Alamanni[1,2], Stefania Farina[1], Gaia Cattadori[4], Valentina Mantegazza[1] and Piergiuseppe Agostoni[1,2]*

[1]*Centro Cardiologico Monzino, IRCCS, Milan, Italy;* [2]*Department of Clinical Sciences and Community Health, Cardiovascular Section, University of Milan, Milan, Italy;* [3]*Department of Biomedical and Clinical Sciences "Luigi Sacco", University of Milan, Milan, Italy; and* [4]*IRCCS Multimedica, Milan, Italy*

LEGGE DI FICK + DISTRIBUZIONE





…grazie per l’attenzione.

Quanto conta l'anemia?

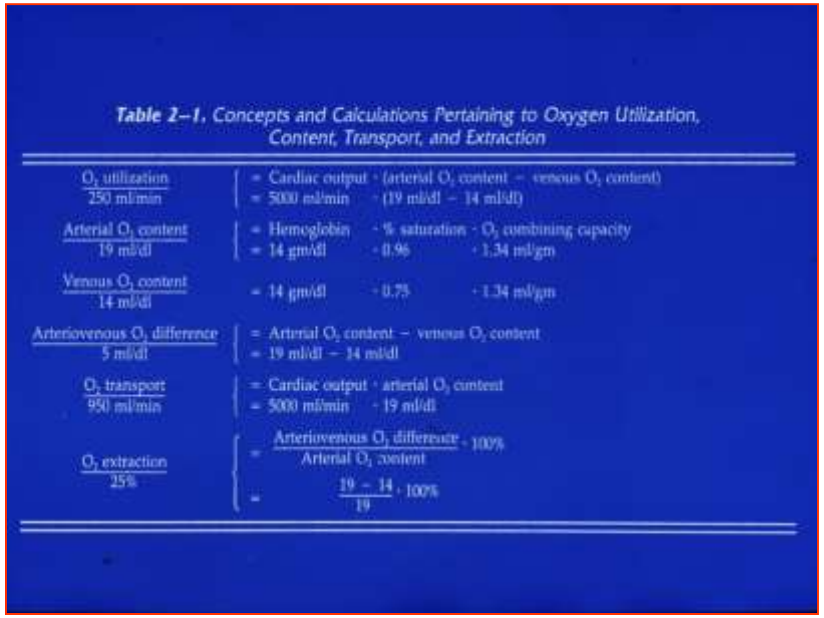


Table 2–1. *Concepts and Calculations Pertaining to Oxygen Utilization, Content, Transport, and Extraction*

O_2 utilization / 250 ml/min	= Cardiac output · (arterial O_2 content − venous O_2 content) = 5000 ml/min · (19 ml/dl − 14 ml/dl)
Arterial O_2 content / 19 ml/dl	= Hemoglobin · % saturation · O_2 combining capacity = 14 gm/dl · 0.96 · 1.34 ml/gm
Venous O_2 content / 14 ml/dl	= 14 gm/dl · 0.75 · 1.34 ml/gm
Arteriovenous O_2 difference / 5 ml/dl	= Arterial O_2 content − venous O_2 content = 19 ml/dl − 14 ml/dl
O_2 transport / 950 ml/min	= Cardiac output · arterial O_2 content = 5000 ml/min · 19 ml/dl
O_2 extraction / 25%	$= \frac{\text{Arteriovenous } O_2 \text{ difference}}{\text{Arterial } O_2 \text{ content}} \cdot 100\%$ $= \frac{19 - 14}{19} \cdot 100\%$

CaO_2 = 1.34 mlxgr Hb

Estrazione periferica O_2 = 75%

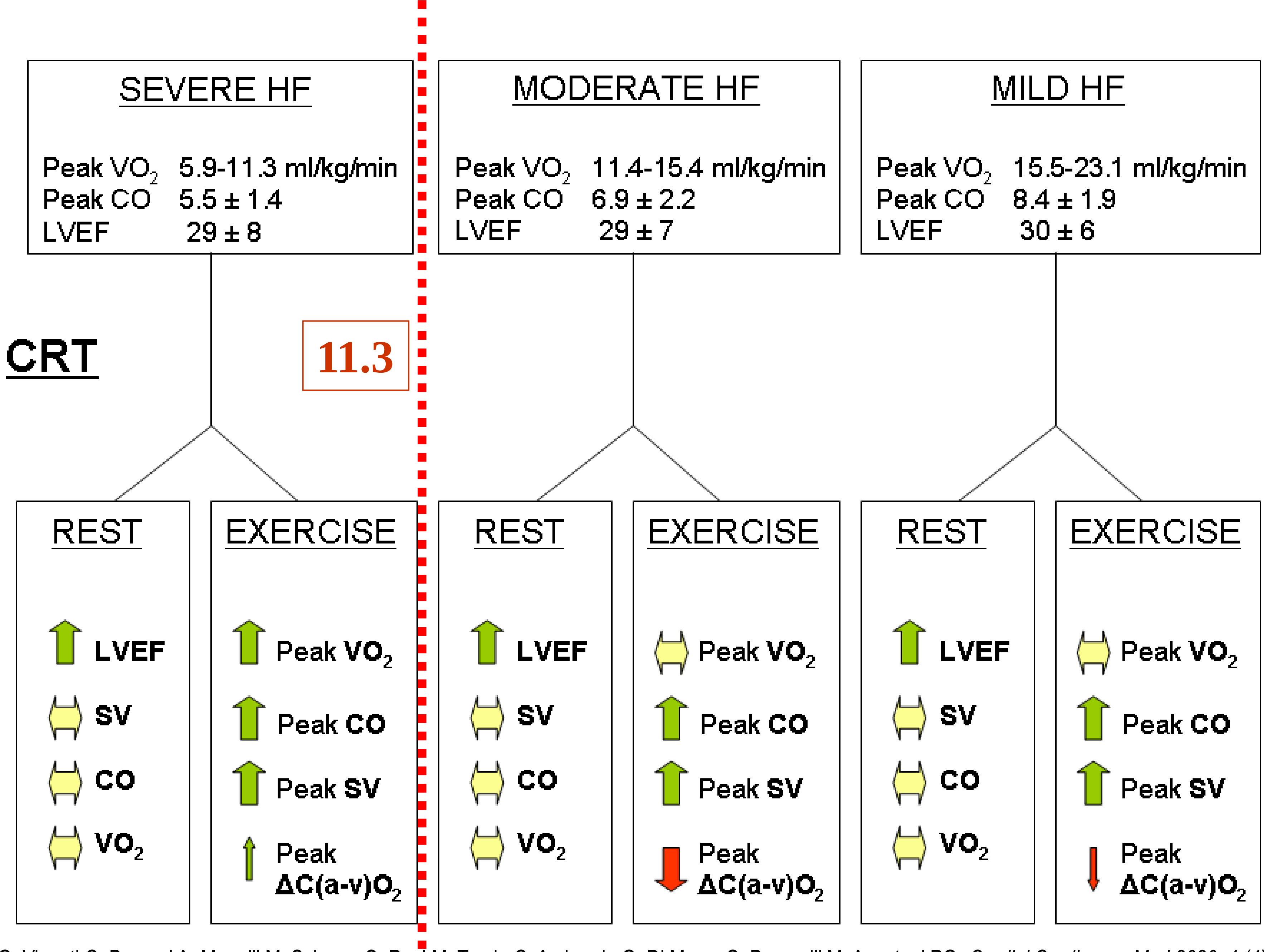
1 gr di Hb porta ai tessuti 1 ml O_2 x dl di sangue

Cardiol Cardiovasc Med 2020; 4 (4): 386-395 *DOI: 10.26502/fccm.92920135*

Research Article

Peak Exercise Cardiac Output but Not Oxygen Uptake Increases in All Heart Failure Patients After Successful Resynchronization Therapy

Gaia Cattadori[1#], Carlo Vignati[2,5#], Alice Bonomi[2], Massimo Mapelli[3,5], Susanna Sciomer[3], Mauro Pepi[2], Claudio Tondo[2], Giuseppe Ambrosio[4], Silvia Di Marco[1], Massimo Baravelli[1], Piergiuseppe Agostoni[2,5*]



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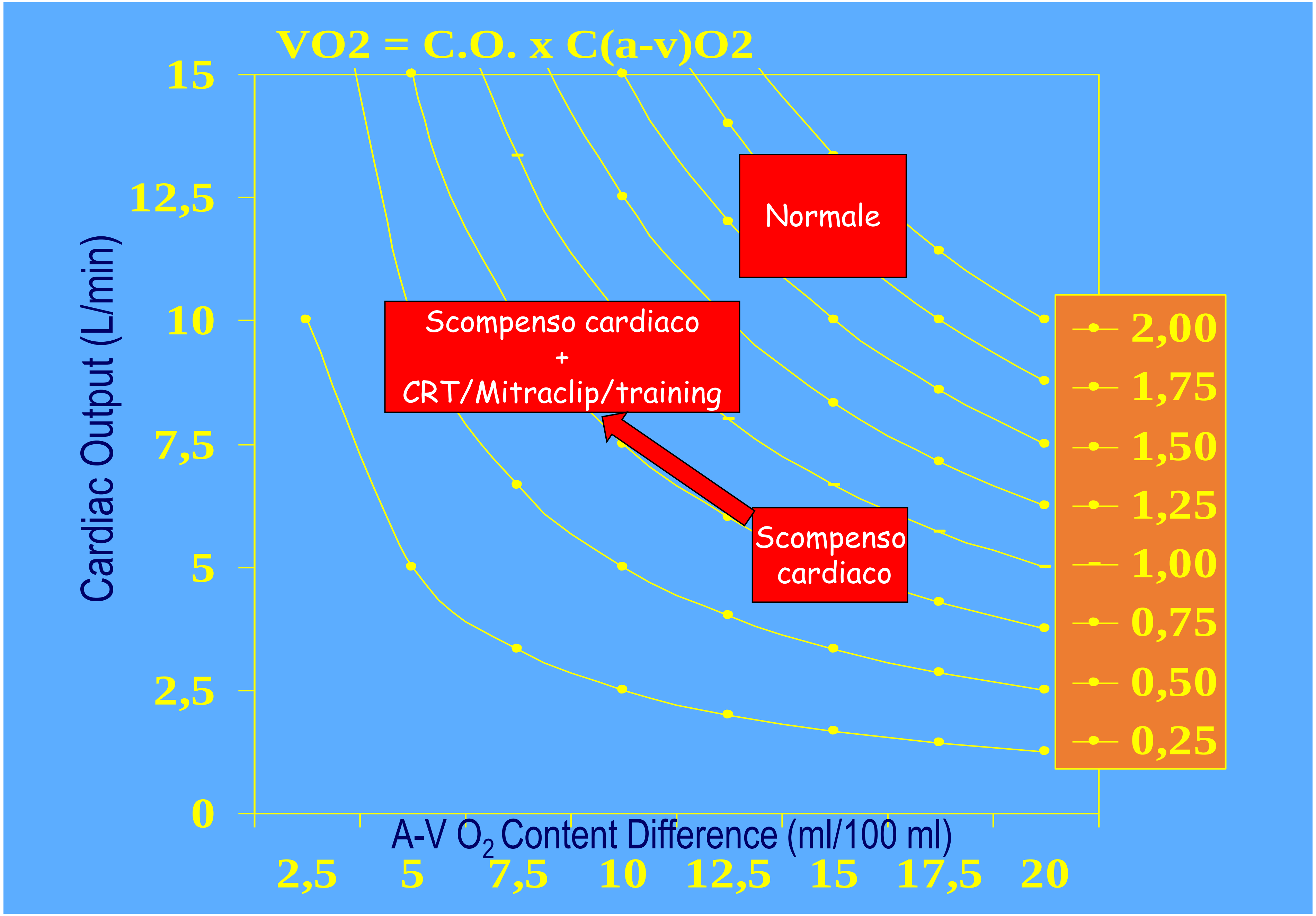
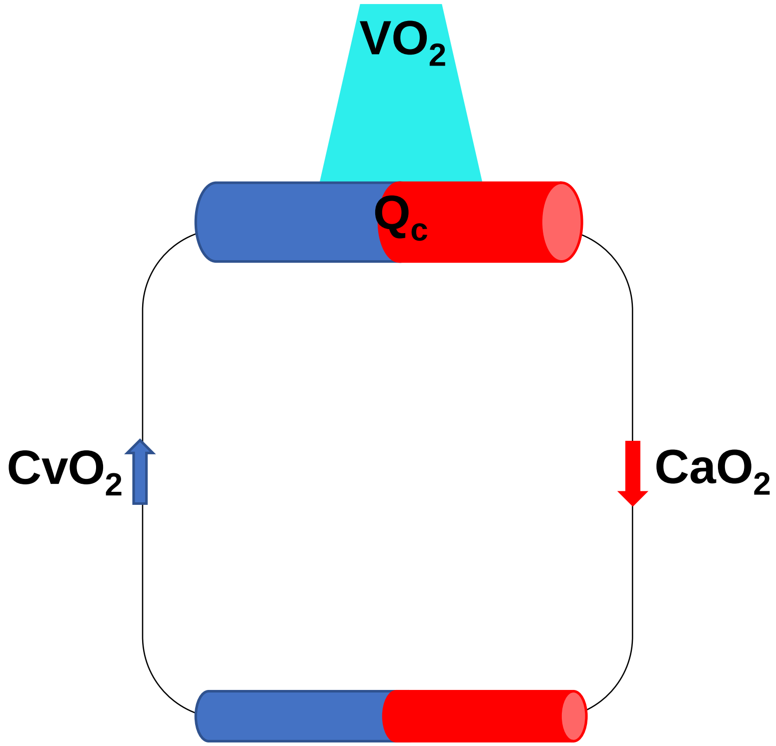
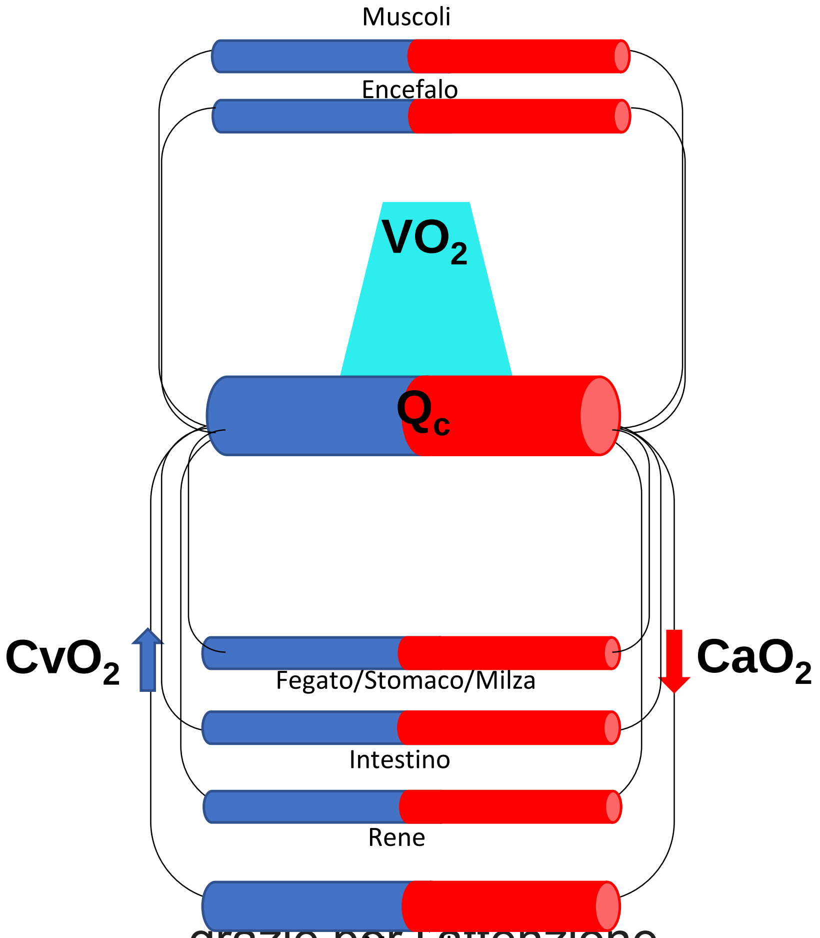

VO2 = C.O. x C(a-v)O2
Cardiac Output (L/min)
15
12,5
10
7,5
5
2,5
0
A-V O2 Content Difference (ml/100 ml)
2,5
5
7,5
10
12,5
15
17,5
20
Normale
Scompenso cardiaco
+
CRT/Mitraclip/training
Scompenso cardiaco
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25

LEGGE DI FICK + DISTRIBUZIONE





…grazie per l'attenzione.

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Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

Hb 13.5 gr/dl

1) Limitazione Cardiogenica (mlVO2)
2) Limitazione "Periferica" (mlVO2)

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

1040 ml/min

Hb 13.5 gr/dl

1) Limitazione Cardiogenica (mlVO2)
2) Limitazione "Periferica" (mlVO2)

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

919 ml/min ← **1040 ml/min**

Hb 13.5 gr/dl

1) Limitazione Cardiogenica (mlVO2)
2) Limitazione "Periferica" (mlVO2)

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

74%

919 ml/min ← **1040 ml/min**

Hb 13.5 gr/dl

1) Limitazione Cardiogenica (mlVO2) → 74%
2) Limitazione “Periferica” (mlVO2)

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

Hb 13.5 gr/dl

74%

919 ml/min ← 1040 ml/min → 121 ml/min

1) Limitazione Cardiogenica (mlVO2)
2) Limitazione "Periferica" (mlVO2)

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a\text{-}v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

Hb 13.5 gr/dl

74% **26%**

919 ml/min ← **1040 ml/min** → **121 ml/min**

1) Limitazione Cardiogenica (mlVO2)
2) Limitazione “Periferica” (mlVO2) → 26%

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a\text{-}v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

74%

26%

919 ml/min ← 1040 ml/min → 121 ml/min

Hb 13.5 gr/dl

- Hb
- SatHb O_2
- pO_2

Gruppo MultiMedica

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	$C(a-v)O_2$ ml/dl
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

74%

26%

919 ml/min ← **1040 ml/min** → **121 ml/min**

Hb 13.5 gr/dl

- Hb
- SatHb O_2
- pO_2

Step	CO L/min	HR b/min	SV ml/b	VO2 ml/min	Diff AV
Basal	4.5	75	60	220	5
Peak	7.9	109	72	1080	14
Peak pred	13.6	154	88	2120	16
Peak %	58	71	82	51	88

Hb 13.5 gr/dl

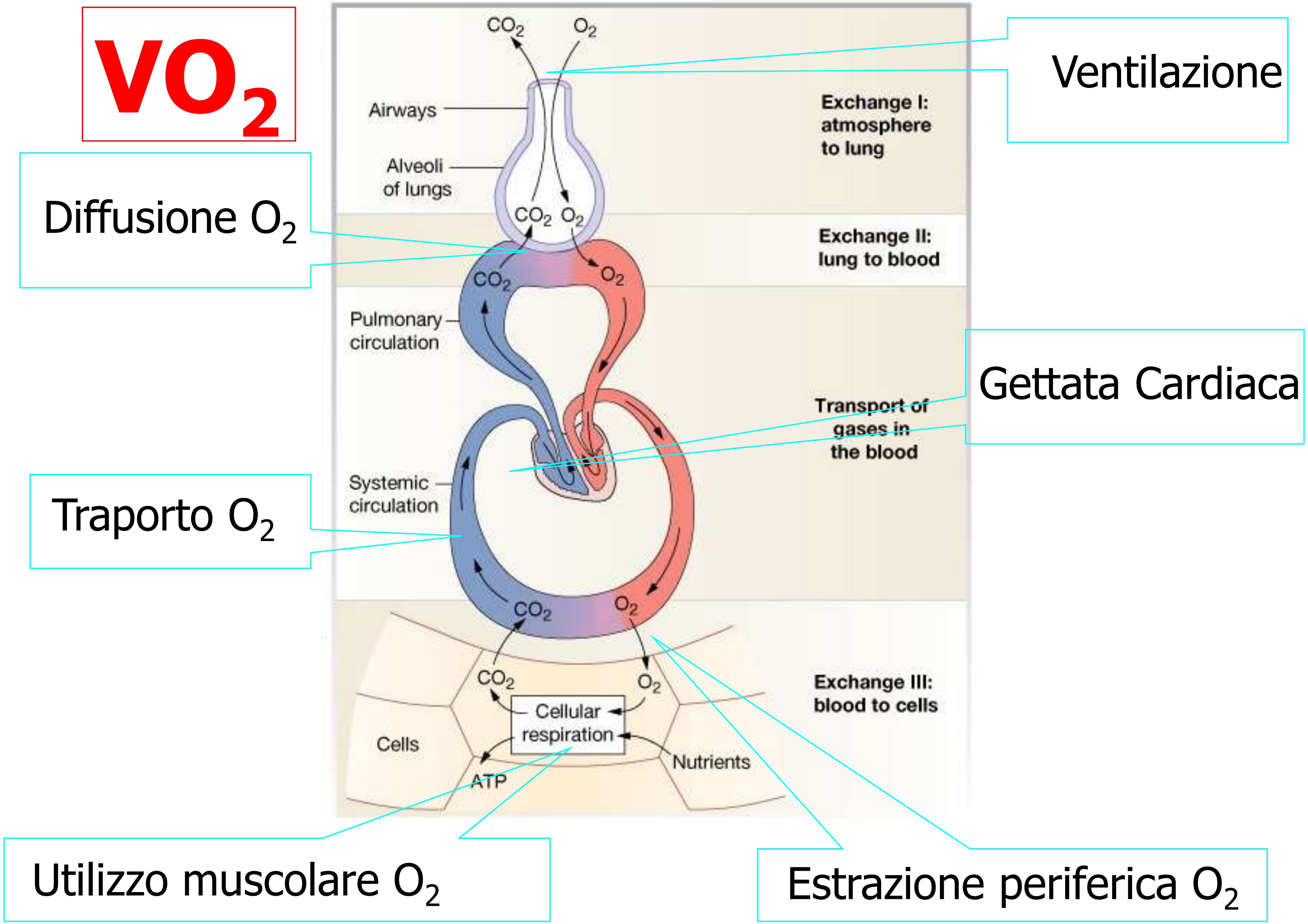
1 gr Hb porta ai tessuti 1 ml O_2 x dl di sangue

2) Limitazione (mlVO2) dovuta all'anemia = CO x anemia= CO x (15-13.5)

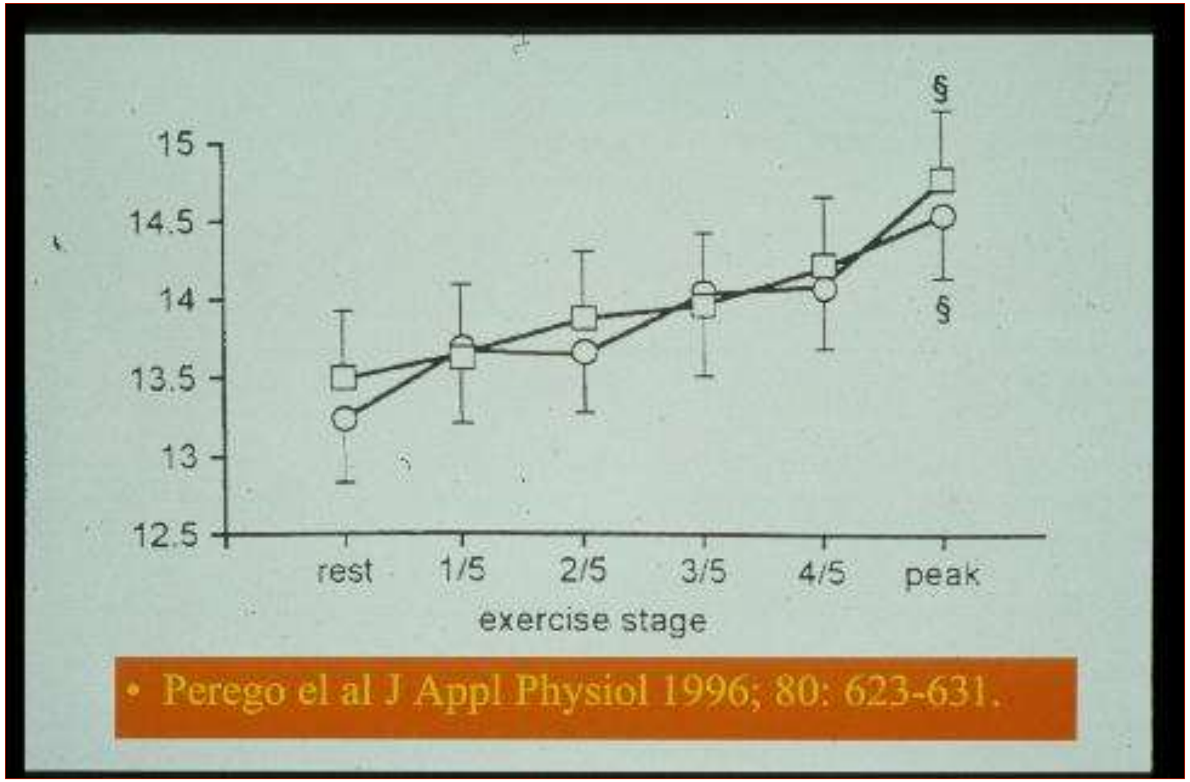
79 x 1.5 = 119 mlVO2

MultiMedica
Gruppo

VO_2



Ventilazione
Diffusione O_2
Gettata Cardiaca
Traporto O_2
Utilizzo muscolare O_2
Estrazione periferica O_2
CO_2
O_2
Airways
Alveoli of lungs
Exchange I: atmosphere to lung
Exchange II: lung to blood
Pulmonary circulation
Transport of gases in the blood
Systemic circulation
Exchange III: blood to cells
Cells
Cellular respiration
Nutrients
ATP



Due possibili meccanismi per incremento Hb:

1. Riduzione plasma
2. Incremento globuli rossi

1. Riduzione plasma

Exercise-Induced Hemoconcentration in Heart Failure Due to Dilated Cardiomyopathy

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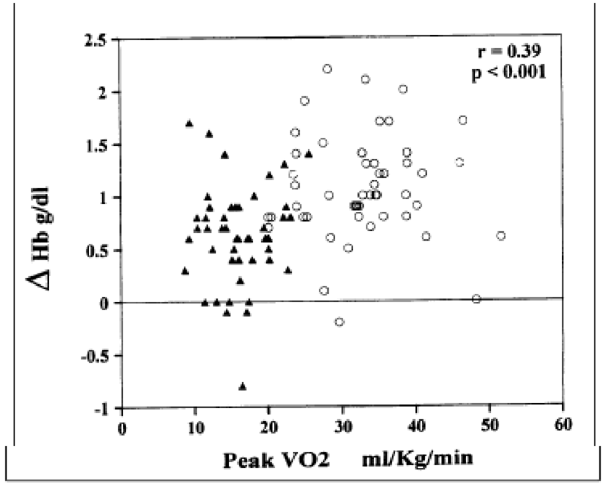

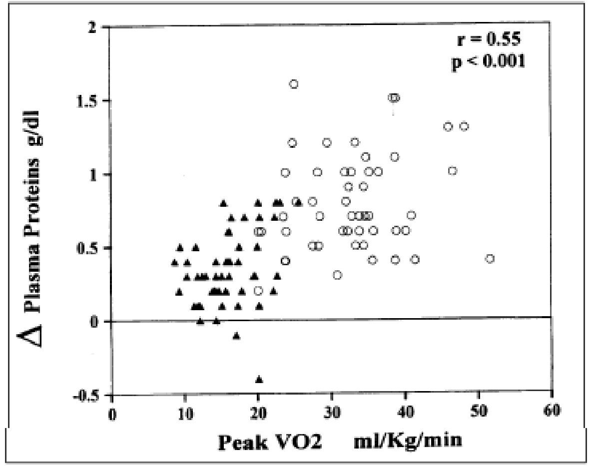

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Agostoni et al. Am J Cardiol 1999

2. Incremento globuli rossi

bjh research paper

Exercise capacity in patients with β-thalassaemia intermedia

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Summary

Thalassaemia intermedia patients can suffer fatigue and exercise capacity reduction, possibly because of anaemia, deconditioning and lack of exercise-induced haemoconcentration. We studied 21 β-thalassaemia intermedia patients, 10 splenectomised (group A) and 11 not splenectomised (group B). Patients were evaluated by cardiopulmonary exercise test with blood sampling for haemoglobin and plasma protein measurements at rest and peak. During exercise, an isolated increase of haemoglobin suggested spleen contraction while a parallel increase of haemoglobin and proteins suggested fluid filtration through capillary wall. Groups were homogeneous for age and gender. Peak oxygen consumption (VO_2) was 22·5 ± 4·4 ml/min/kg (51 ± 14%) and 24·3 ± 7·0 (53 ± 12%) in groups A and B respectively [not significant (NS)]. At rest, haemoglobin was 8·8 g/dl in both groups. Exercise-induced increment was 0·4 ± 0·2 and 1·0 ± 0·4 g/dl ($P < 0{\cdot}001$) for haemoglobin and 4·0 ± 3·0 and 5·0 ± 4·0 g/l (NS) for proteins, in groups A and B respectively. Anaemia was the major cause of peak VO_2 reduction (1097 ± 260 ml/min). However, anaemia did not explain the entire exercise capacity reduction, suggesting the presence of muscular deconditioning. Exercise capacity is reduced in β-thalassaemia intermedia because of anaemia and muscular deconditioning. Spleen contraction does not significantly influence exercise capacity although exercise-induced haemoconcentration was greater in patients with spleen.

Keywords: anaemia, haemoglobin, oxygen consumption, muscular deconditioning, spleen contraction.

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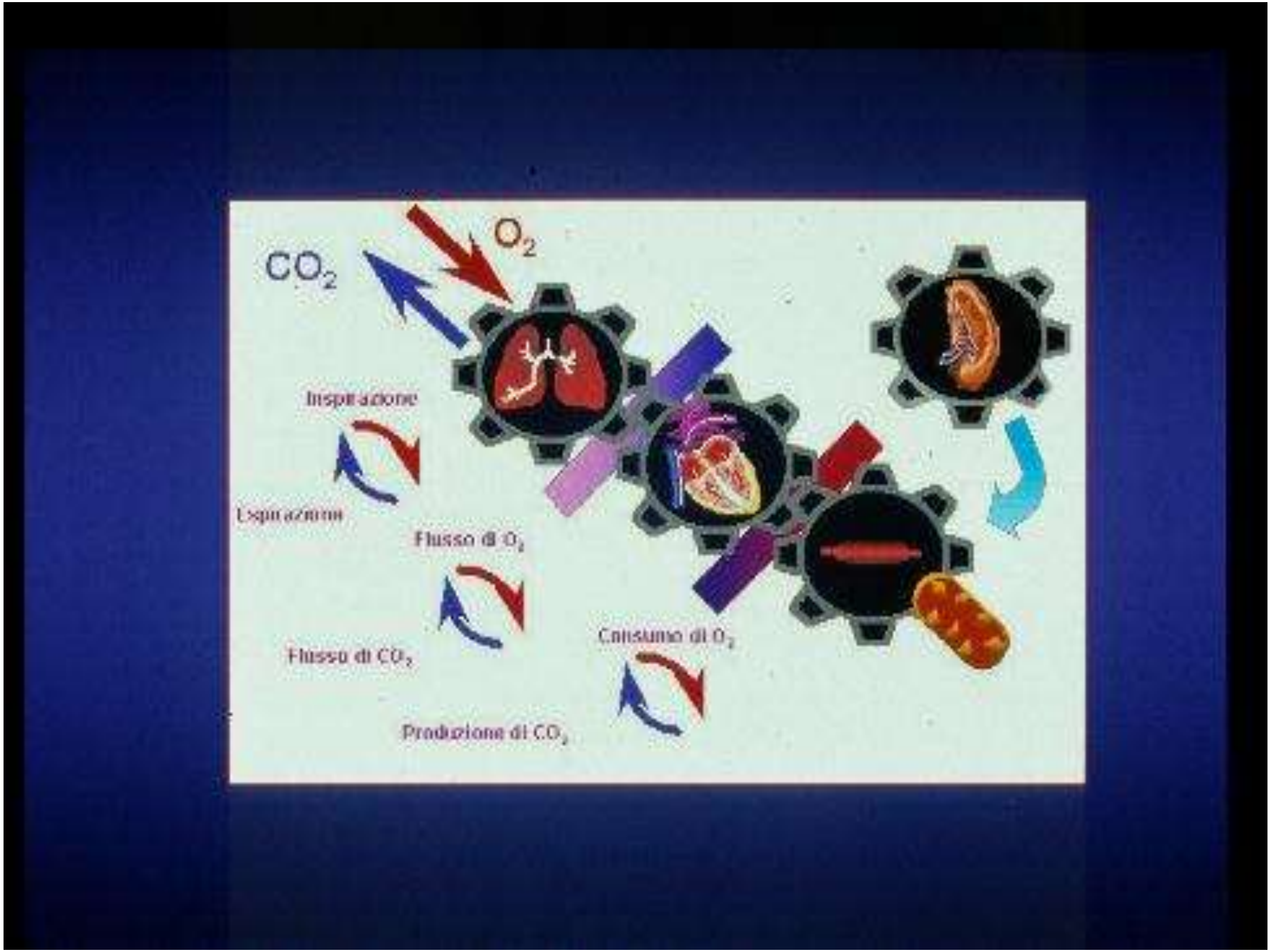
Agostoni et al. B J Haematol 2005



CO_2
O_2
Inspirazione
Espirazione
Flusso di O_2
Flusso di CO_2
Consumo di O_2
Produzione di CO_2

Ex 2) Rehabilitation Patients

CARDIOTHORACIC ANESTHESIOLOGY:
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Postoperative Anemia and Exercise Tolerance After Cardiac Operations in Patients Without Transfusion: What Hemoglobin Level Is Acceptable?

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Background. Restrictive transfusion strategies have been suggested for cardiac surgical patients, leading to various degrees of postoperative anemia. This study investigates the exercise tolerance during rehabilitation of cardiac surgical patients who did not receive transfusions, with respect to their level of postoperative anemia.

Methods. This observational study started in January 2010 and ended in May 2010 in 2 rehabilitation hospitals and 2 large-volume cardiac surgical hospitals. The study population was 172 patients who did not receive transfusions during cardiac surgical operations with cardiopulmonary bypass and subsequently followed a rehabilitation program in 1 of the 2 rehabilitation hospitals. No patient received a transfusion during the rehabilitation hospital stay. Exercise tolerance was measured using the 6-minute walk test at admission and discharge from the rehabilitation hospital. The level of anemia at admission to the rehabilitation hospital was tested as an independent predictor of exercise tolerance within a model inclusive of other possible confounders.

Results. Patients with values of hemoglobin less than 10 g/dL at admission to the rehabilitation institute had a significantly ($p = 0.007$) worse performance on the 6-minute walk test than patients with higher values (258 ± 106 vs 306 ± 101 meters). This functional gap was completely recovered during a normal rehabilitation period. Other independent factors affecting exercise tolerance were age, sex, and albumin concentration.

Conclusions. Postoperative anemia with hemoglobin levels of 8 to 10 g/dL is well tolerated in patients who have not received a transfusion and induces only a transient impairment of exercise tolerance.

(Ann Thorac Surg 2011;92:25–31)

Ex 2) Rehabilitation Patients

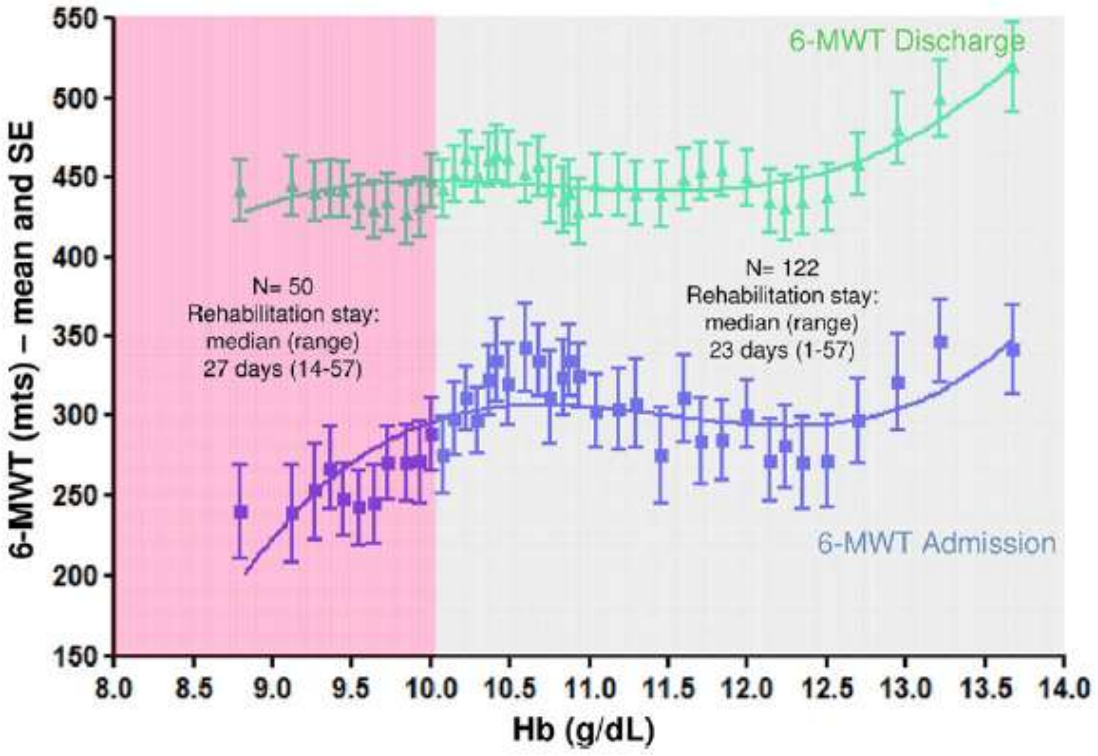

Fig 1. Exercise tolerance upon admission (blue line) and discharge (green line) from the rehabilitation hospital in patients without transfusions. The performance is dependent on the Hb value for values below 10 g/dL (pink area) and independent in patients with higher Hb values upon admission (gray area). (6-MWT = 6-minute walk test; Hb = hemoglobin; SE = standard error.)

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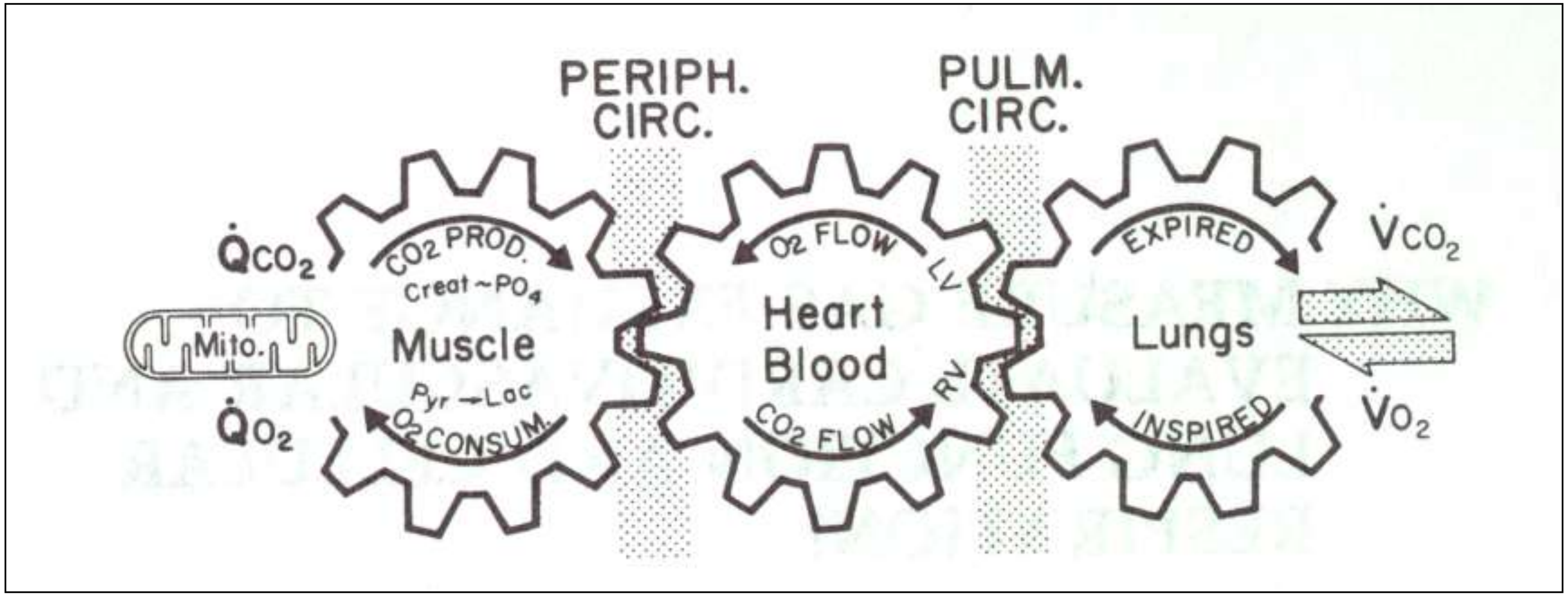
VO_2



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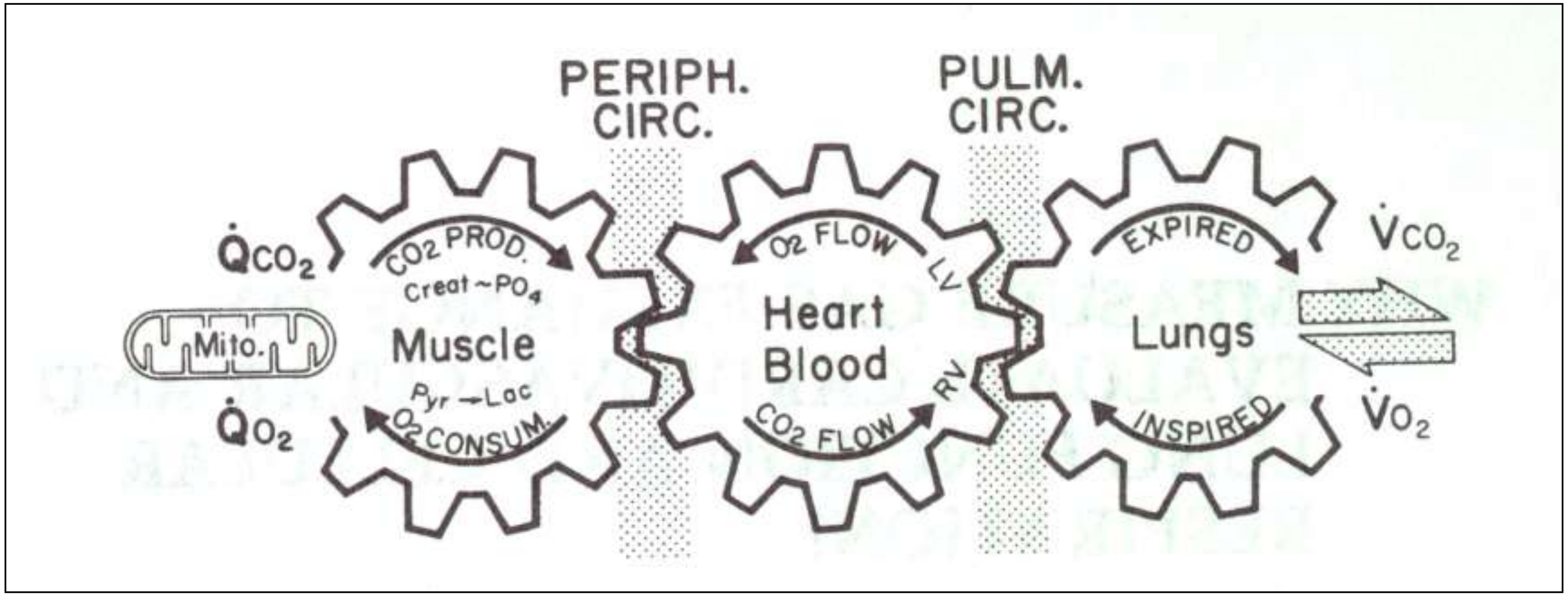
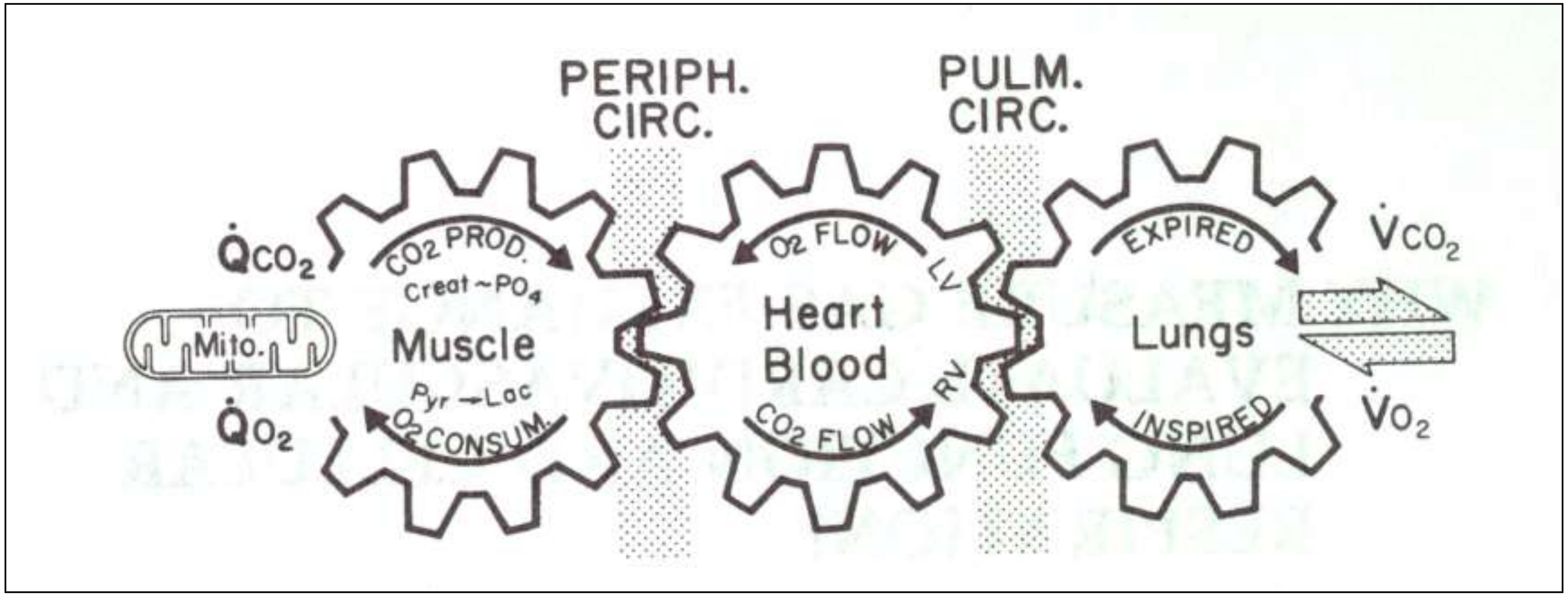
VO_2



$VO_2 =$
$VE\ (FiO_2 - FeO_2)$

VO_2

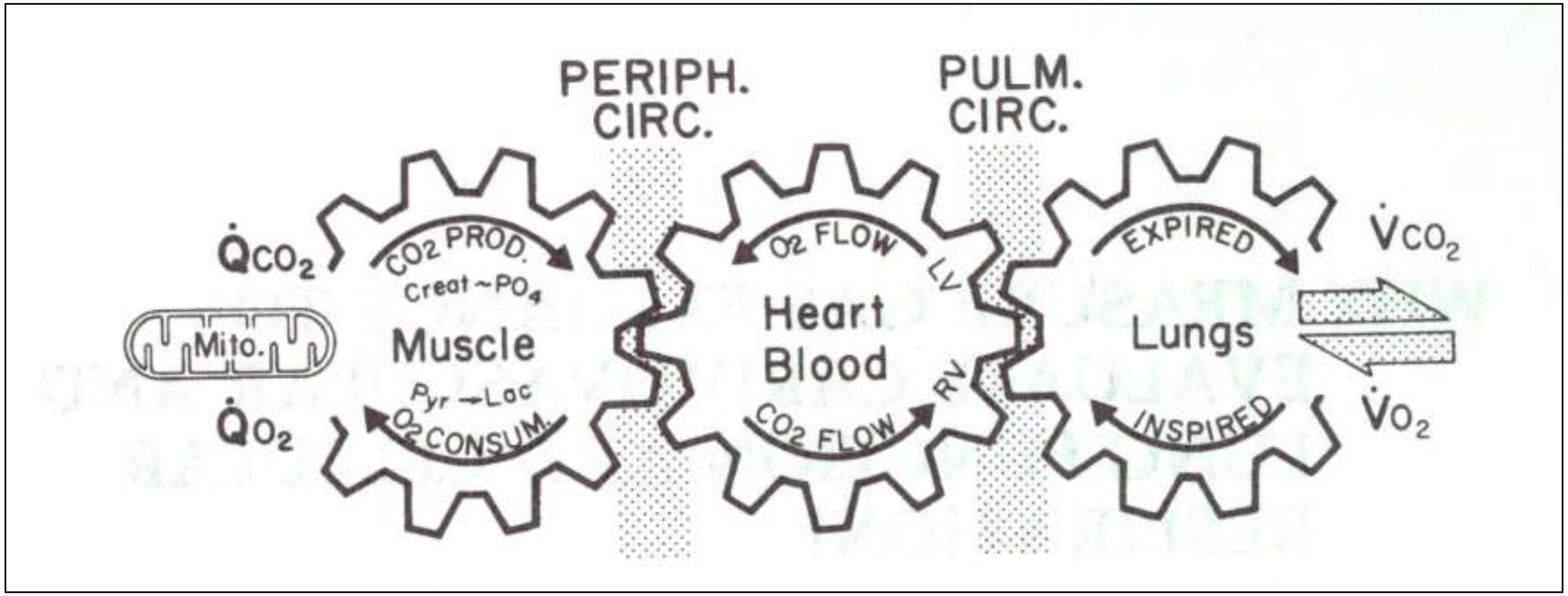


$VO_2 =$
$D(pcapO_2 – pmitO_2)$

$VO_2 =$
$VE\ (FiO_2 – FeO_2)$

VO_2

$VO_2 =$
$CO \times C(a\text{–}v)O_2$



$VO_2 =$
$D(pcapO_2\text{–}pmitO_2)$

$VO_2 =$
$VE\ (FiO_2\ \text{–}FeO_2)$

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VO_2

CO

- Gettata sistolica
- Frequenza cardiaca

X

Ex ↑

$C(a\text{-}v)O_2$

- Hb
- SatHb O_2
- pO_2

VO_2

CO **X** Ex ↑ $C(a-v)O_2$

- Gettata sistolica
- Frequenza cardiaca

HF
20%
20%
60%

- Hb
- SatHb O_2
- pO_2

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Perego GB et al. J Appl Physiol 1996

VO_2

CO **X** **$C(a\text{-}v)O_2$**

- Gettata sistolica
- Frequenza cardiaca

Ex ↑

HF

20%
20%
60%

- Hb
- SatHb O_2
- pO_2

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Perego GB et al. J Appl Physiol 1996