Rəhimə Qabulova

Ürək çatışmazlığında kardiopulmonar yük testi

Cardiopulmonary exercise test in HF

29 İyun 2024

15:15 – 15:30

ÜRƏK ÇATIŞMAZLIĞINDA KARDİOPULMONAR YÜK TESTİ

CARDİOPULMONARY EXERCİSE TEST İN HF

MD, Ph.D., Associate Professor R.İ.Gabulova

III Ürək çatışmazlığında yeniliklər konqresi

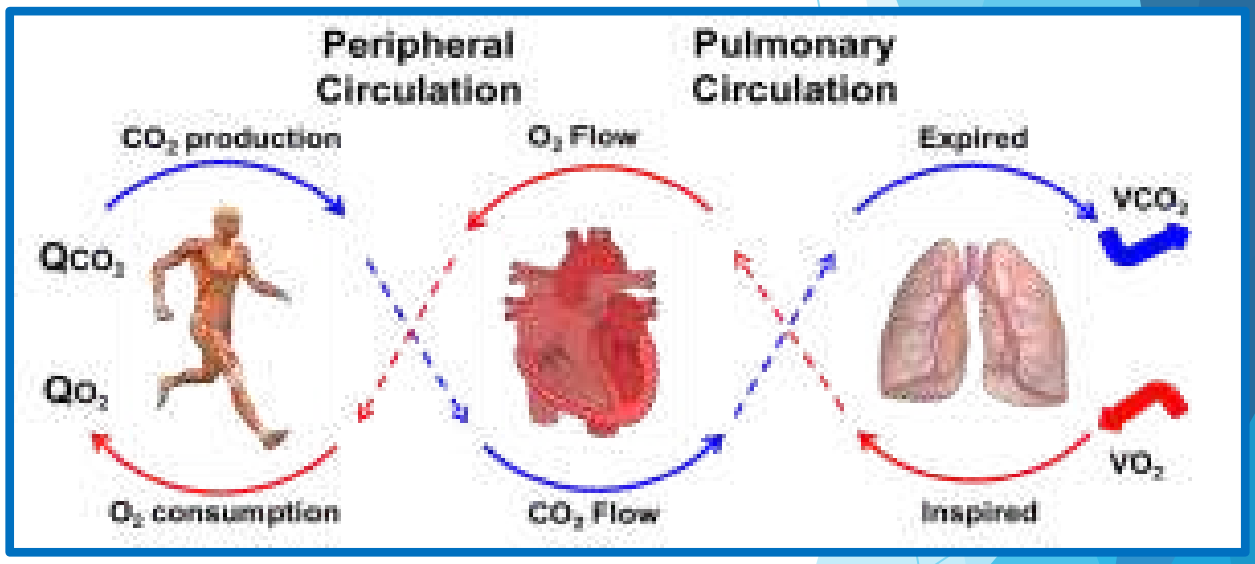
Bakı
28-29 iyun, 2024

Cardiopulmonary exercise testing (CPET) – Kardiopulmonar yük testi

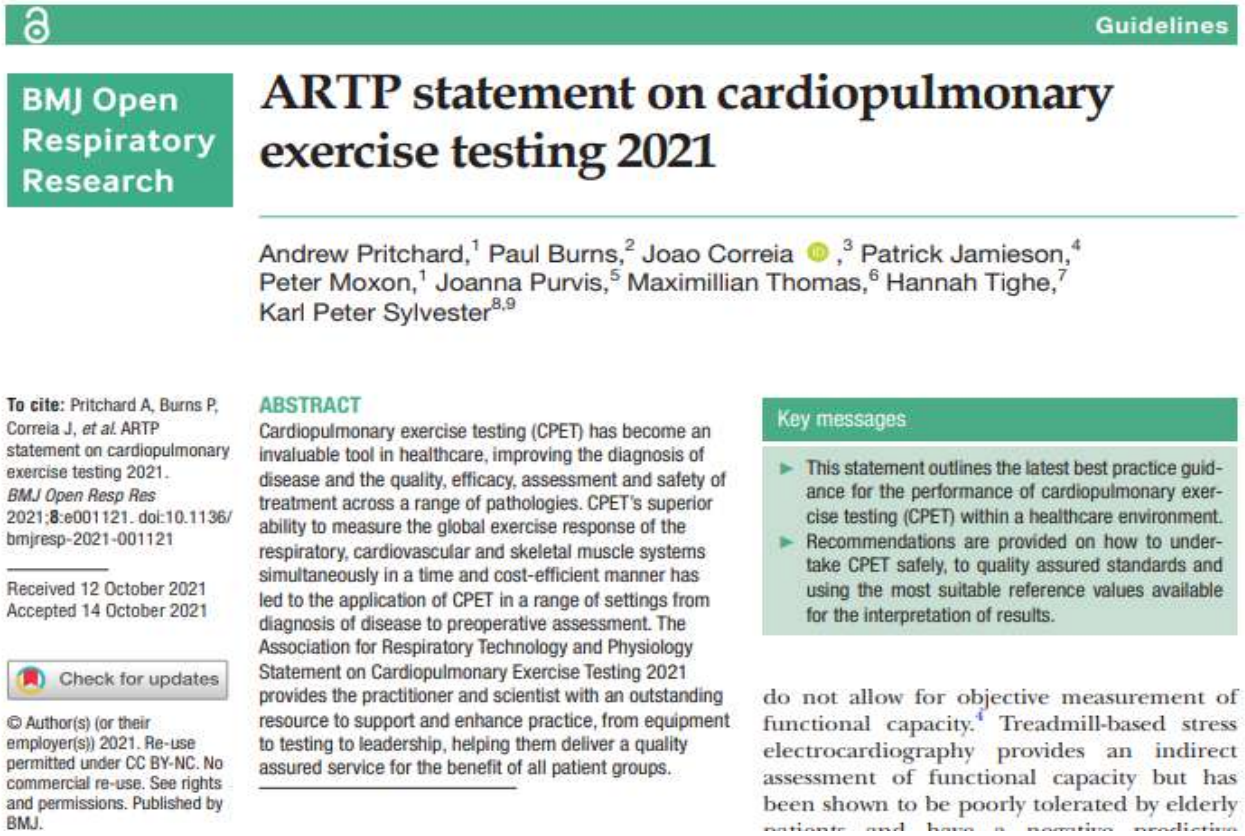
Əsas məqsədi:

Ürək, ağciyər və əzələlərin fiziki stresə qarşı fizioloji cavabının öyrənilməsidir.

Fiziki yükə qarşı CV, respirator və əzələlərin cavabı - kardiorespirator sağlamlıq (CR - fitness) (*R.Ross, 2016*).



ASSOCIATION FOR RESPIRATORY TECHNOLOGY AND PHYSIOLOGY – RESPİRATOR TEXNOLOGİYA VƏ FİZİOLOGİYA ASSOSİASİYASI



Guidelines

BMJ Open Respiratory Research

ARTP statement on cardiopulmonary exercise testing 2021

Andrew Pritchard,[1] Paul Burns,[2] Joao Correia ,[3] Patrick Jamieson,[4] Peter Moxon,[1] Joanna Purvis,[5] Maximillian Thomas,[6] Hannah Tighe,[7] Karl Peter Sylvester[8,9]

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Check for updates

ABSTRACT

Cardiopulmonary exercise testing (CPET) has become an invaluable tool in healthcare, improving the diagnosis of disease and the quality, efficacy, assessment and safety of treatment across a range of pathologies. CPET's superior ability to measure the global exercise response of the respiratory, cardiovascular and skeletal muscle systems simultaneously in a time and cost-efficient manner has led to the application of CPET in a range of settings from diagnosis of disease to preoperative assessment. The Association for Respiratory Technology and Physiology Statement on Cardiopulmonary Exercise Testing 2021 provides the practitioner and scientist with an outstanding resource to support and enhance practice, from equipment to testing to leadership, helping them deliver a quality assured service for the benefit of all patient groups.

Key messages

- This statement outlines the latest best practice guidance for the performance of cardiopulmonary exercise testing (CPET) within a healthcare environment.
- Recommendations are provided on how to undertake CPET safely, to quality assured standards and using the most suitable reference values available for the interpretation of results.

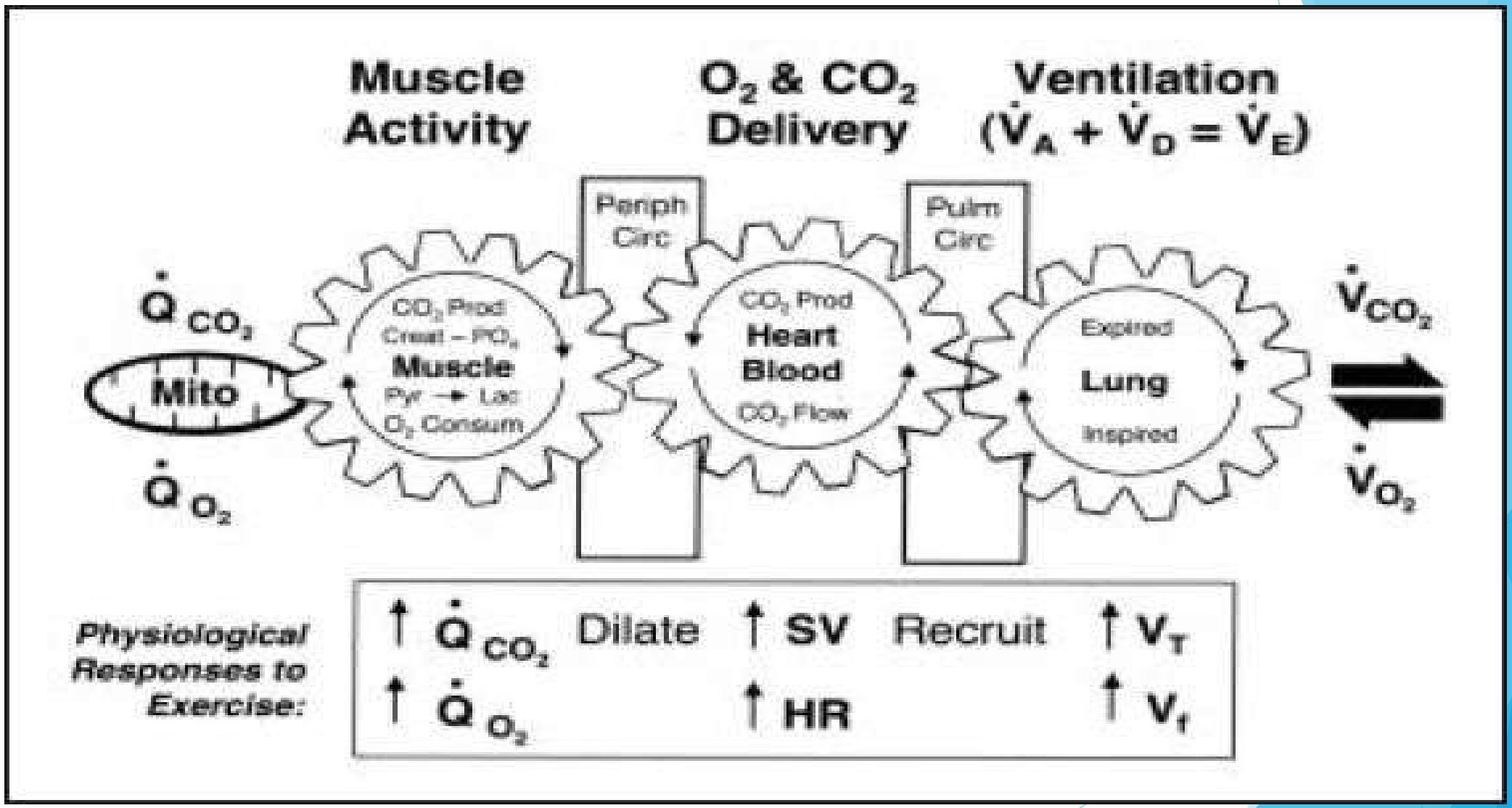
do not allow for objective measurement of functional capacity.[4] Treadmill-based stress electrocardiography provides an indirect assessment of functional capacity but has been shown to be poorly tolerated by elderly

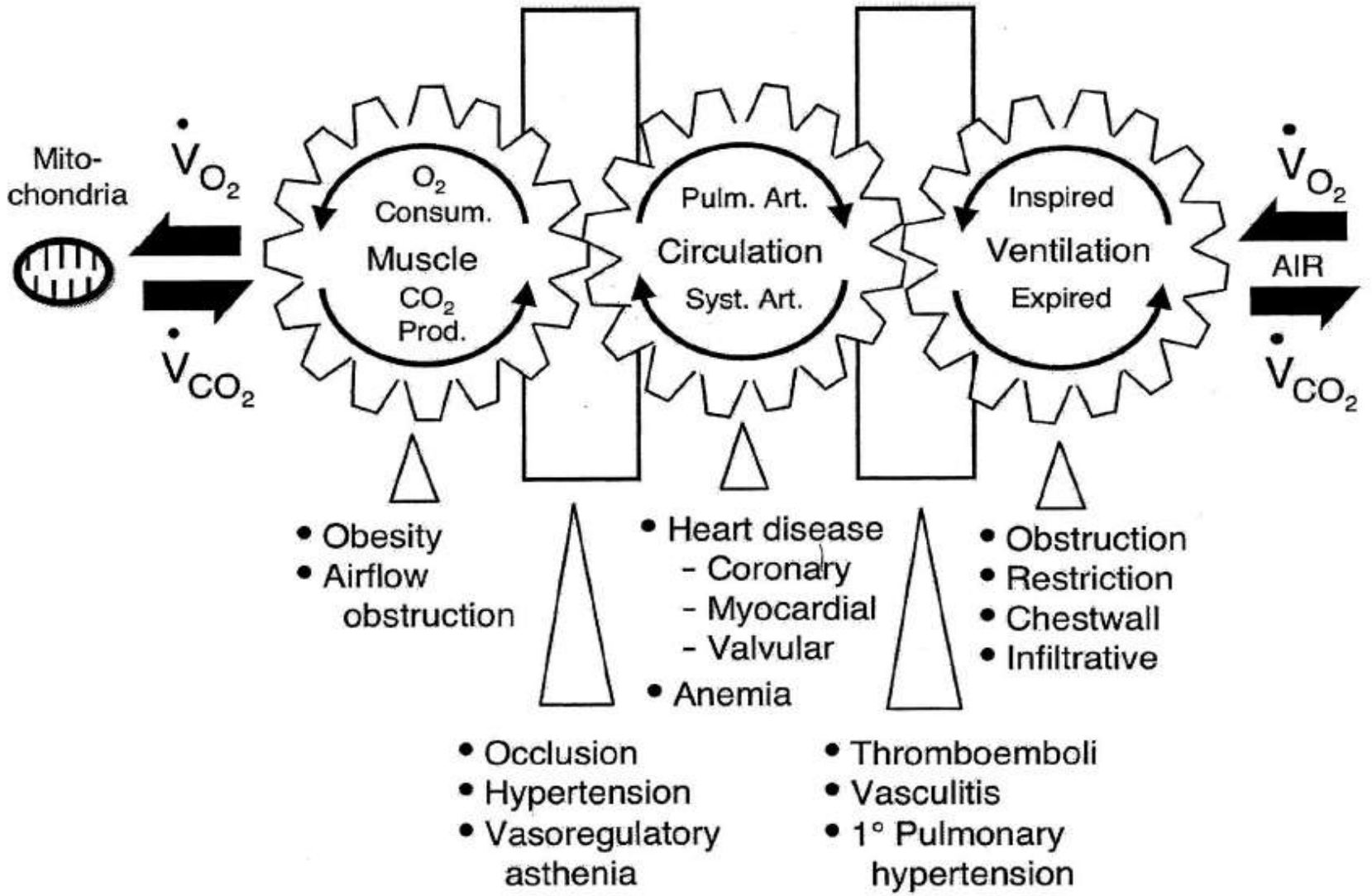
CPET istifadəsi üçün göstərişlər

- **Təngnəfəsliyin səbəbinin müəyyənləşdirilməsi**
- **Ürək-damar xəstəliklərinin qiymətləndirilməsi**
- **Tənəffüs xəstəliklərinin qiymətləndirilməsi**
- **Əməliyyat öncəsi müayinə**
- **Fiziki məşqlərin dozalanması**
- **Əlilliyin qiymətləndirilməsi**
- **Fiziki yükə tolerantlığının qiymətləndirilməsi.**

Adapted from the American Thoracic Society and American College of Chest Physicians.

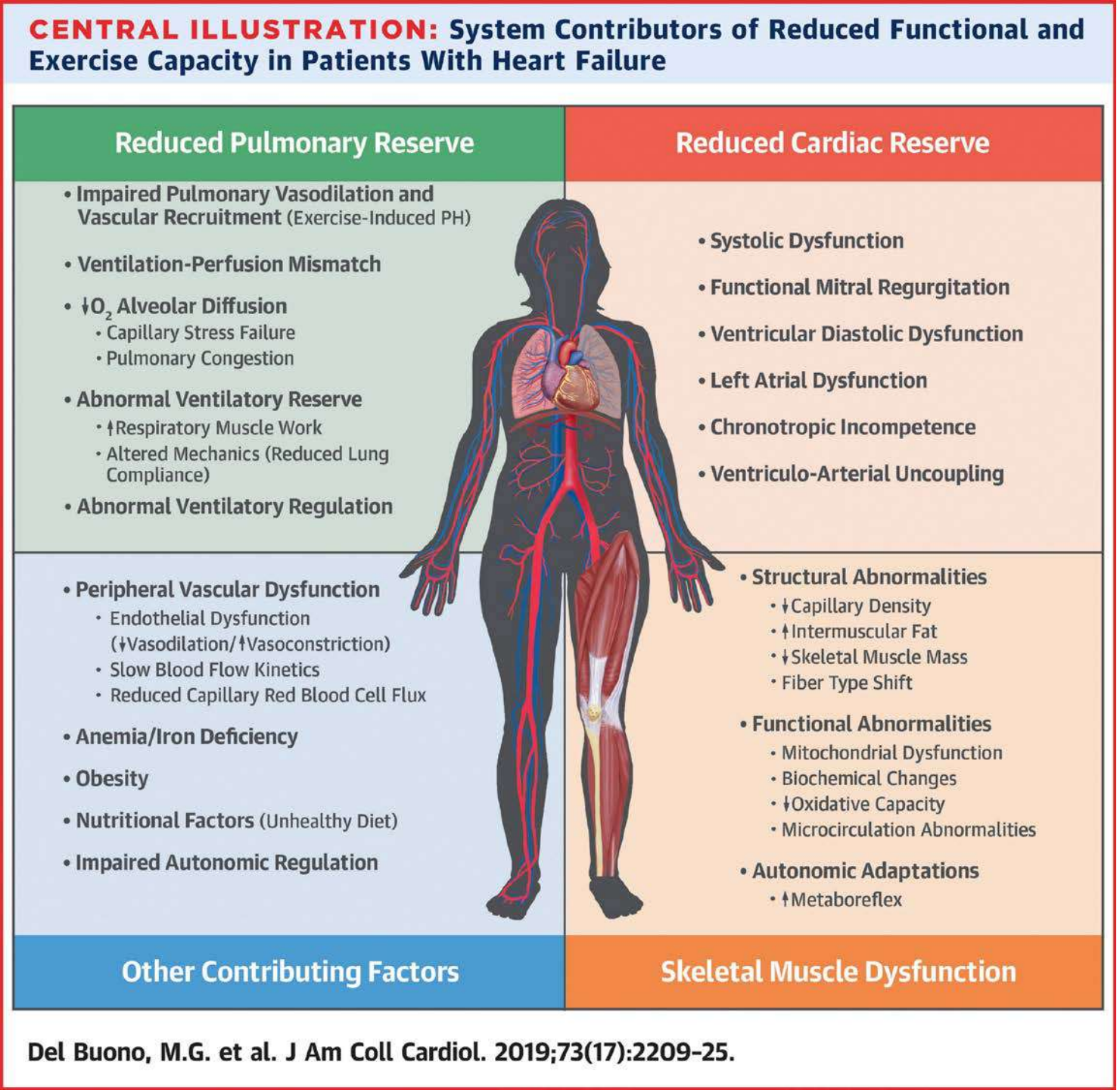
https://bmjopenrespres.bmj.com/content/8/1/e001121


Muscle Activity
O2 & CO2 Delivery
Ventilation (V̇A + V̇D = V̇E)
Q̇ CO2
Mito
Q̇ O2
CO2 Prod
Creat – PO2
Muscle
Pyr → Lac
O2 Consum
Periph Circ
CO2 Prod
Heart
Blood
CO2 Flow
Pulm Circ
Expired
Lung
Inspired
V̇CO2
V̇O2
Physiological Responses to Exercise:
↑ Q̇ CO2
↑ Q̇ O2
Dilate
↑ SV
↑ HR
Recruit
↑ VT
↑ Vf



Milani R V et al. Circulation. 2004;110:e27-e31

American Heart Association.



Del Buono, M.G. et al. J Am Coll Cardiol. 2019;73(17):2209-25.

ÜÇ zamanı funksional və fiziki iş (exercise capacity) qabiliyyətinin azalma səbəbləri

Table 3 American College of Cardiology/American Heart Association guidelines for cardiopulmonary exercise testing

Class	Indication
I (indicated)	1 Evaluation of exercise capacity and response to treatment in patients with heart failure who are being considered for heart transplantation
	2 Assistance in the differentiation of cardiac versus pulmonary limitations as a cause of exercise-induced dyspnoea or impaired exercise capacity when the cause is uncertain
IIa (good supportive evidence)	Evaluation of exercise capacity when indicated for medical reasons in patients for whom the estimates of exercise capacity from exercise test time or work rate are unreliable
IIb (weak supportive evidence)	1 Evaluation of the patient's response to specific therapeutic interventions in which improvement of exercise tolerance is an important goal or end point
	2 Determination of the intensity for exercise training as part of comprehensive cardiac rehabilitation
III (not indicated)	Routine use to evaluate exercise capacity

Albouaini, K., Egred, M., & Alahmar, A. (2007). Cardiopulmonary exercise testing and its application. *Heart*, *93*(10), 1285. https://doi.org/10.1136/hrt.2007.121558

KPYT (CPET) ilə hansı parametrlər ölçülə bilər?

CPET zamanı alınan nəticələr üç parametrin ölçülməsi ilə hesablanır:

- **O2 istehlakı (VO2)**
- **Karbon qazının xaric olunması (VCO2)**
- **Ventilyasiya (VE)**

Alınan nəticələr orqanizmin fiziki yük zamanı qaz mübadiləsinin müxtəlif xüsusiyyətlərini təyin etməyə imkan verir.

American Thoracic Society/
American College of Chest Physicians

ATS/ACCP Statement on Cardiopulmonary Exercise Testing

THIS JOINT STATEMENT OF THE AMER
WAS ADOPTED BY THE ATS BOARD O
NOVEMBER 1, 2001

TABLE 10. MEASUREMENTS D

Measurements
External work
Metabolic gas exchange
Cardiovascular
Ventilatory
Pulmonary gas exchange
Acid–base
Symptoms

Definition of abbreviations: ABGs = A
f_R = respiratory frequency; HR = hea
dioxide pressure; Pa_{O_2} = arterial oxyge
Sa_{O_2} = arterial oxygen saturation; Sp_{O_2}
$\dot{V}_E$ = minute ventilation; V_D/V_T = ra
WR = work rate. Adapted by permiss

- **Work rate – yerinə yetirilmiş yükün həcmi (Watt-la)**
- **Metabolik qaz mübadiləsi göstəriciləri:**
  - ✓**O2 istehlakı (VO2) və CO2 istehsalı (VCO2)**
  - ✓**Respiratory exchange ratio - Tənəffüs mübadilə nisbəti - (RER=VCO2/VO2)**
- **Ventilyasiya göstəriciləri: SpO2, VE , VT, tənəffüs sayı (RR), ventilyasiya ekvivalentləri O2 (VE/VO2) və CO2 (VE/VCO2).**
- **Ürək-damar göstəriciləri: O2 pulse, ÜVS, EKQ-də ST seqmentindəki dəyişikliklər və qan təzyiqinin qeyri-invaziv monitorlanması**

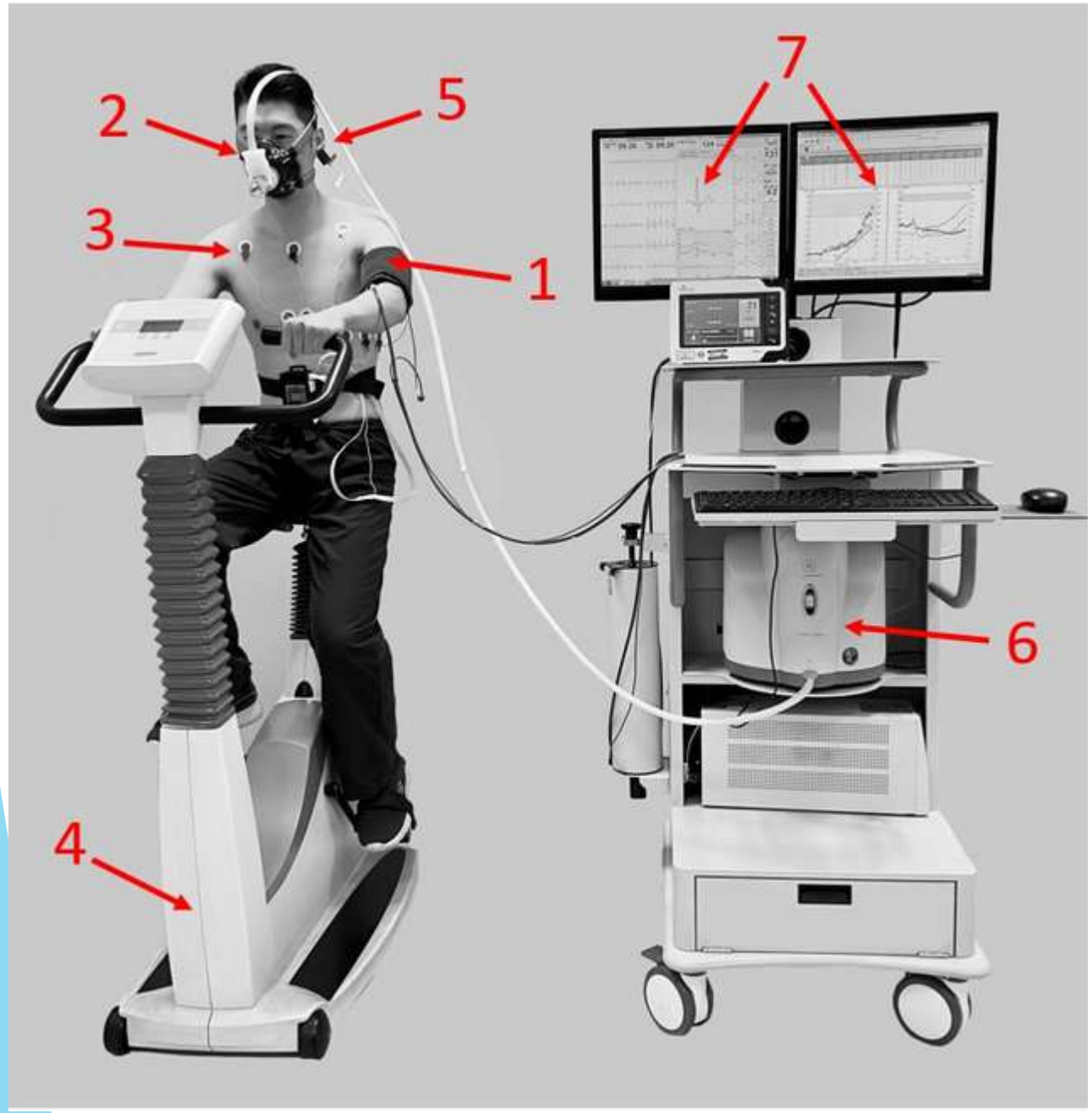
Table 2 Normal cardiopulmonary exercise testing variables

Variables	Normal value
Peak oxygen content (PVo_2)	>84% Predicted
Ventilatory anaerobic threshold (VAT)	>40% PVo_2 (40–80%)
Maximum heart rate (HRmax)	>90% Age predicted
Heart rate reserve (HRR)	<15 Beats/min
Blood pressure (BP)	<220/90
O_2 pulse (Vo_2/HR)	>80%
Ventilatory reserve (VR)	MVV−VEmax >11 litres or VEmax/MVV × 100 <85%
Respiratory rate (RR)	<60 Breaths/min
Minute ventilation/carbon dioxide output ratio (VE/Vco_2) at VAT	<34

MVV, maximal voluntary ventilation; VE, expired ventilation.

Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

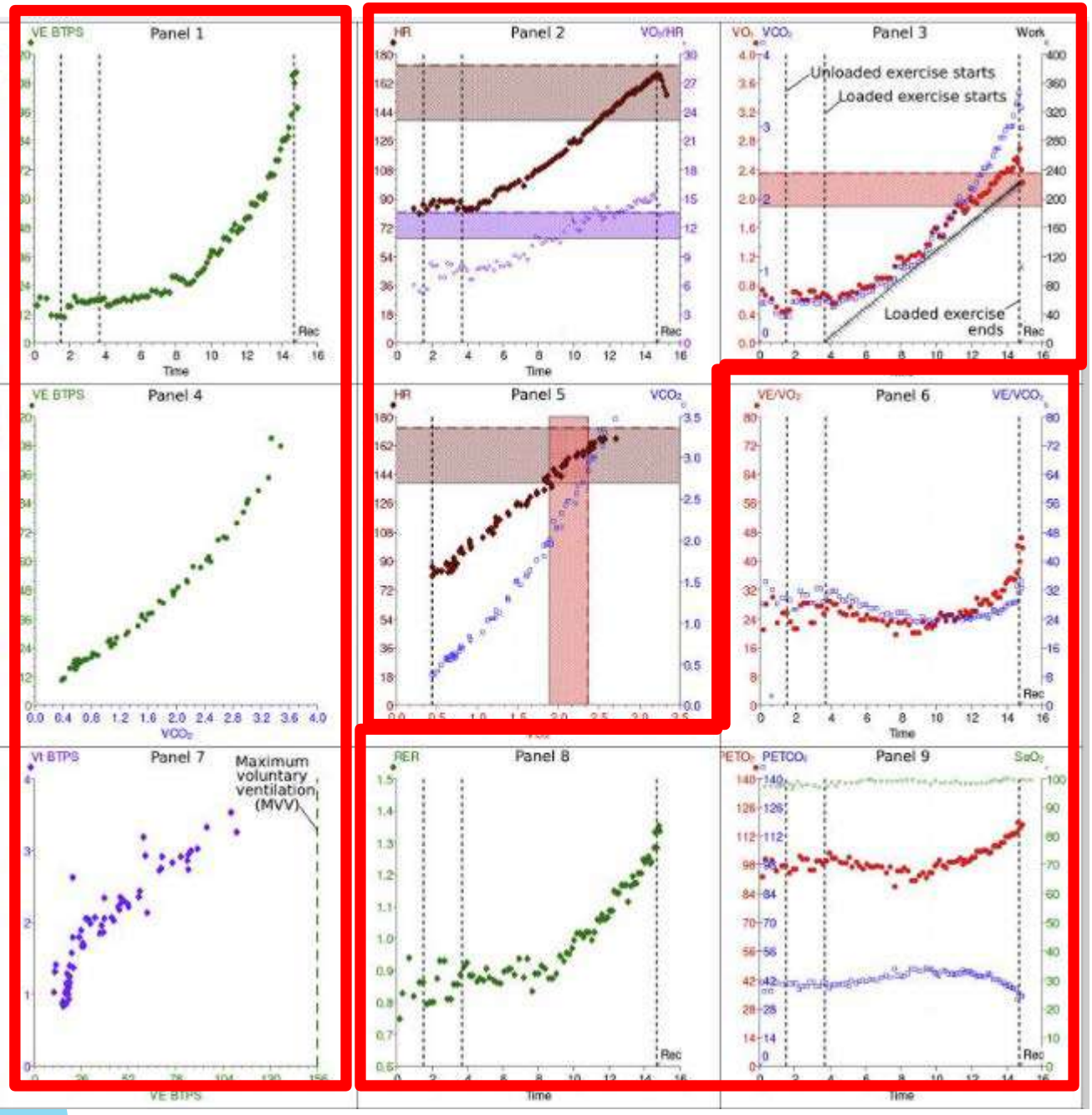
- **Göstəricilərin dəyişməsi klinik nəticələrin pisləşməsi ilə əlaqədardır (*mortality, morbidity, hospitalization, admission to İCU, length of hospital stay*)**



Standart avadanlıq

1 – AT monitoru;
2- maska, həcm sensoru və qas analizatoru;
3 - 12-lead ECG;
4 - erqometr (veloerqometr, tredmil, s.);
5 - puls oksimetr,
6- qas analizatoru;
7- nəfəs və ECG göstəriciləri ilə displey.

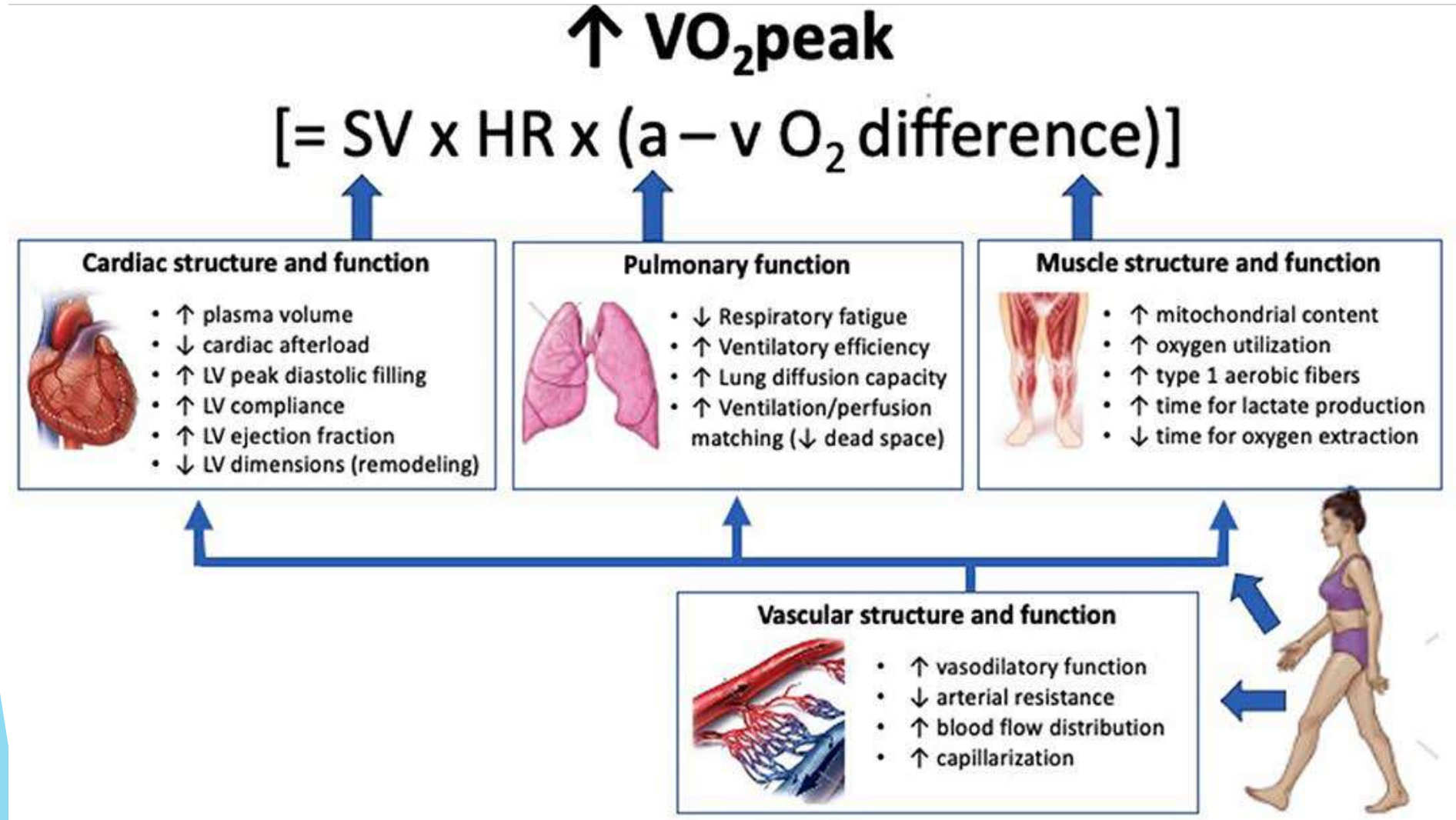
https://www.researchgate.net/publication/356238804_ARTP_statement_on_cardiopulmonary_exercise_testing_2021/figures?lo=1



9 - qrafikli panel

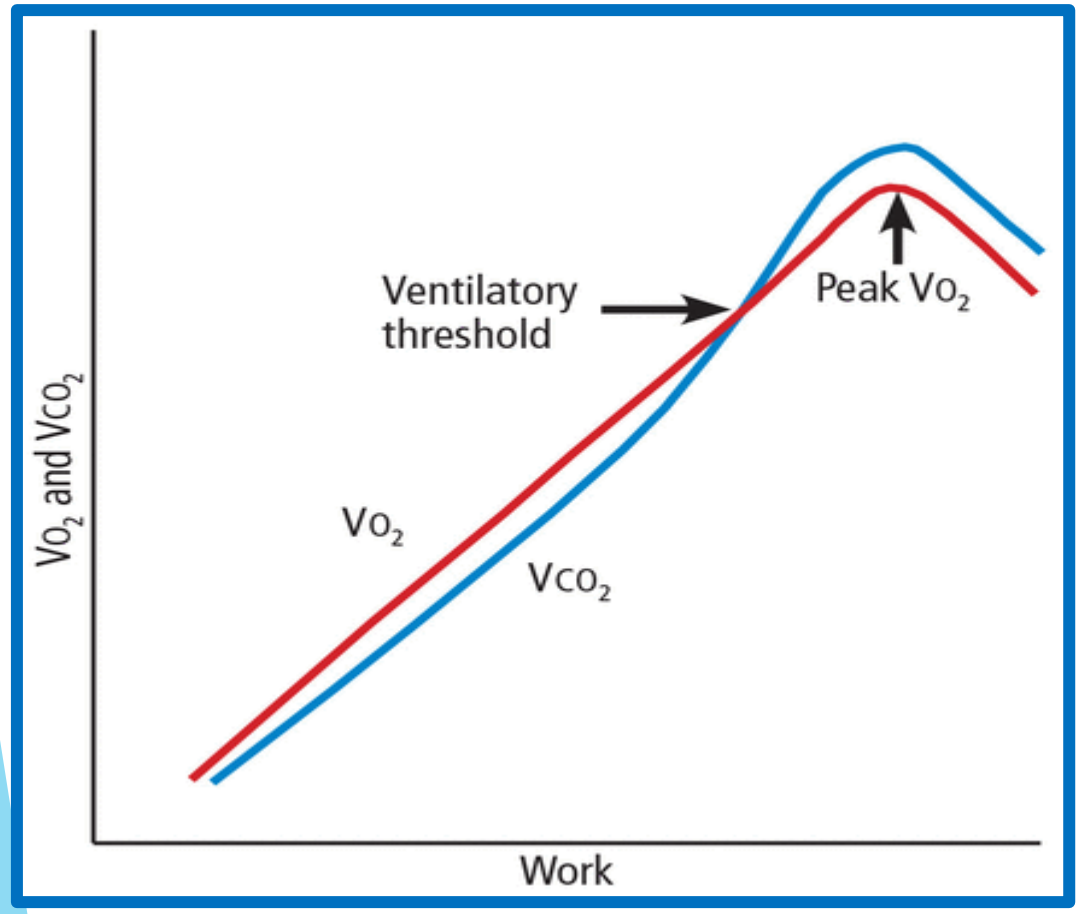
- UDS - 2, 3, 5;
- Ventilyasiya - 1, 4, 7;
- Ventilyasiya –perfuziya münasibəti 6, 8, 9.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7807922/



https://clinicalgate.com/cardiopulmonary-response-to-exercise-in-health-and-disease/#s0020

Peak VO2 - Pik oksigen istehlakı



Göstəricilər yaşa, cinsə, fiziki qabiliyyət səviyyəsinə, çəkiyə və xəstəliyə görə çox dəyişir. Maximal VO2 yaşlılarda< 20 ml/kq/dəq; elit idmançılarda >90.

Proqnozlaşdırılan pik göstəricinin (Peak VO2) ≥85%-nin əldə olunması əlverişli hesab olunur;

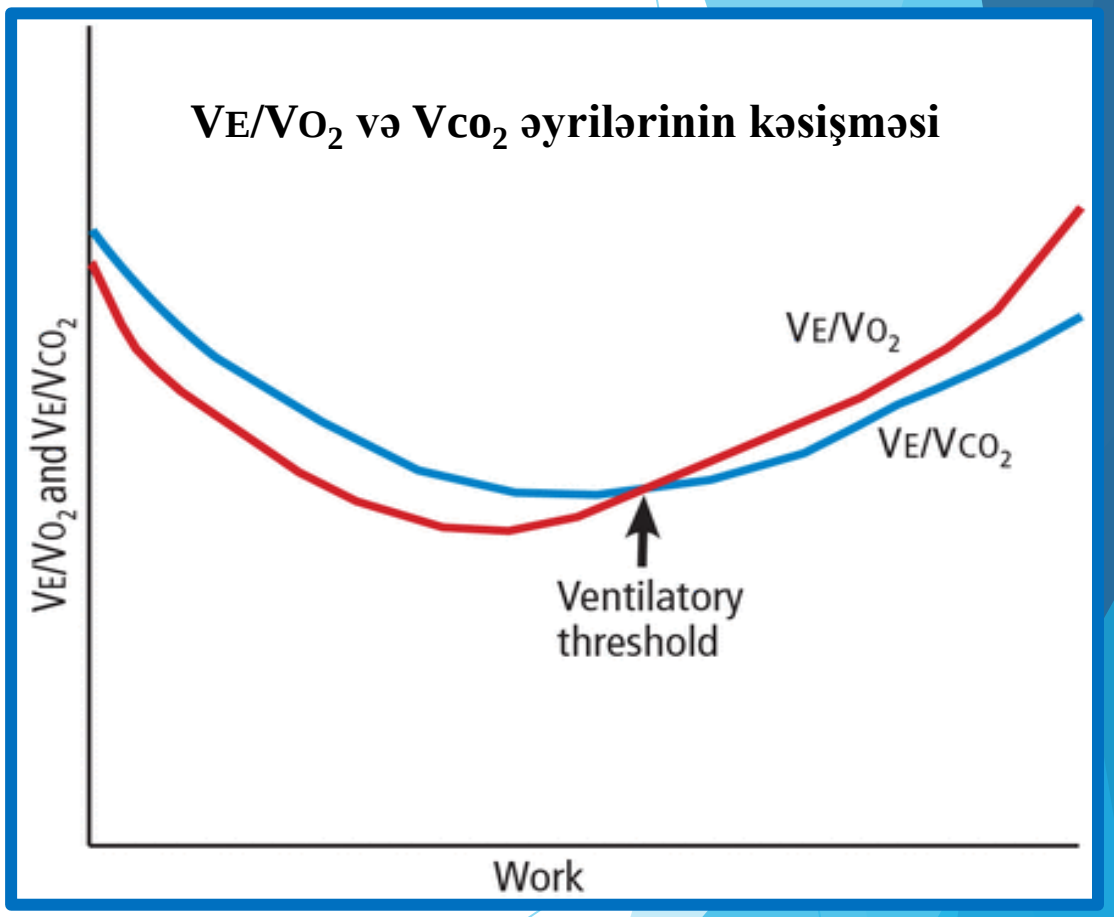
Ürək çatışmazlığı üçün 14 ml/kq/dəq əlverişsiz proqnozu əks etdirir.

https://www.ccjm.org/content/84/2/161/tab-figures-data

Ventilyasiya həddi (Ventilatory threshold - VT)

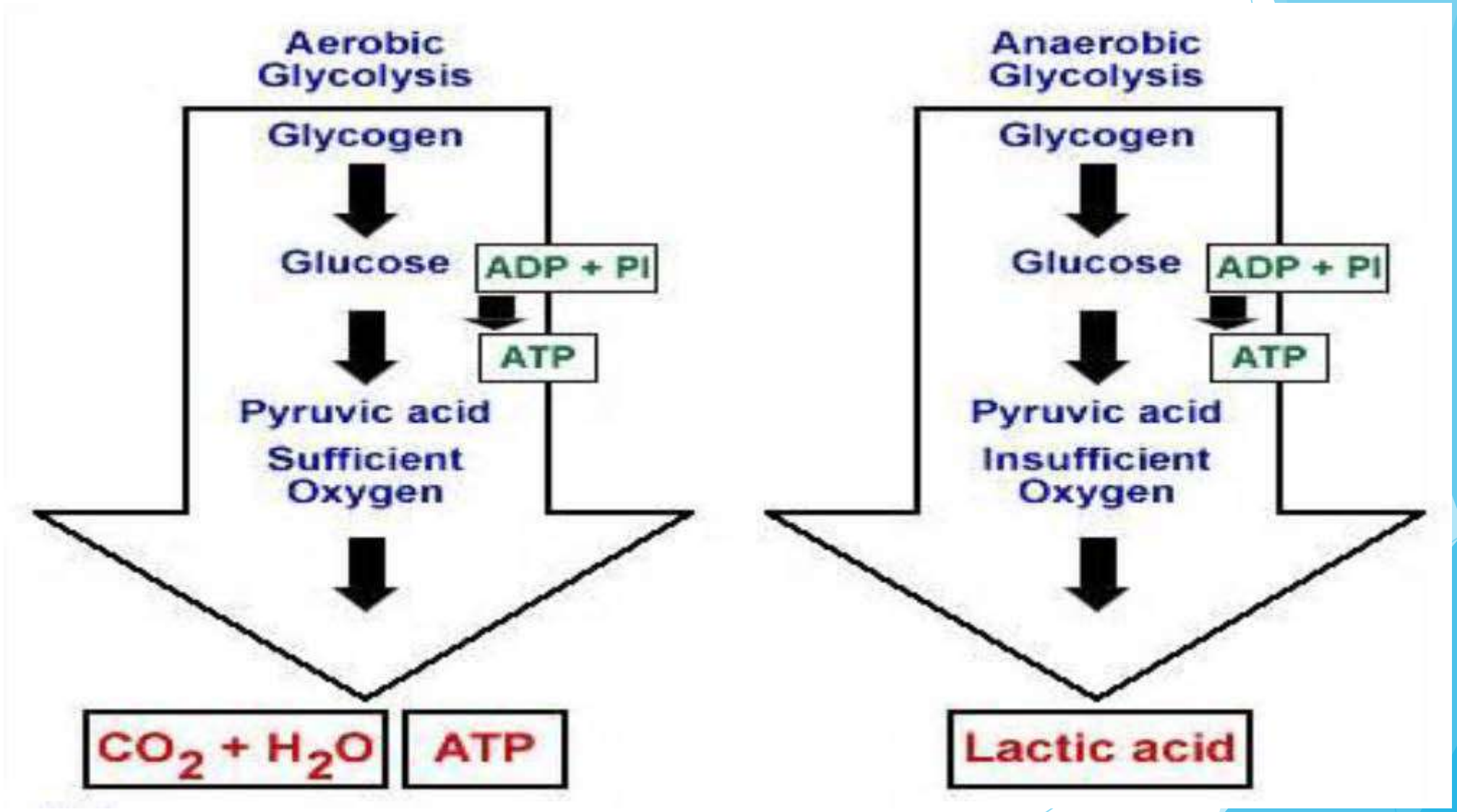
Anaerob metabolizmin artdığı nöqtədir.

- **VT-də VO2 istehlakı səviyyəsi maxVO2 səviyyəsinin 40-60% - ni təşkil edir.**
- **Göstəricinin <40% olması fiziki yükə tolerantlığın aşağı olması və ya patologiyadır.**

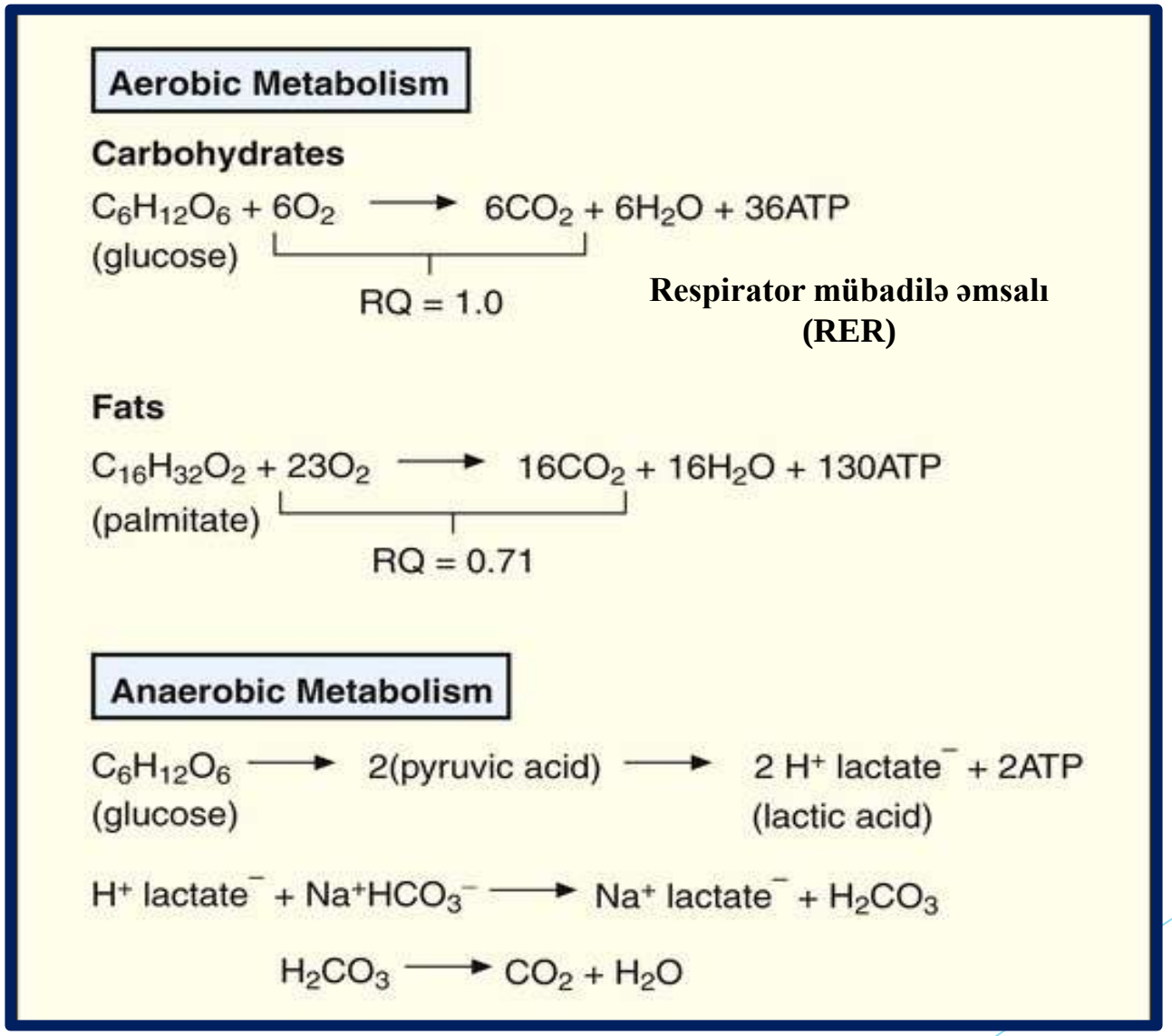


https://www.ccjm.org/content/84/2/161/tab-figures-data

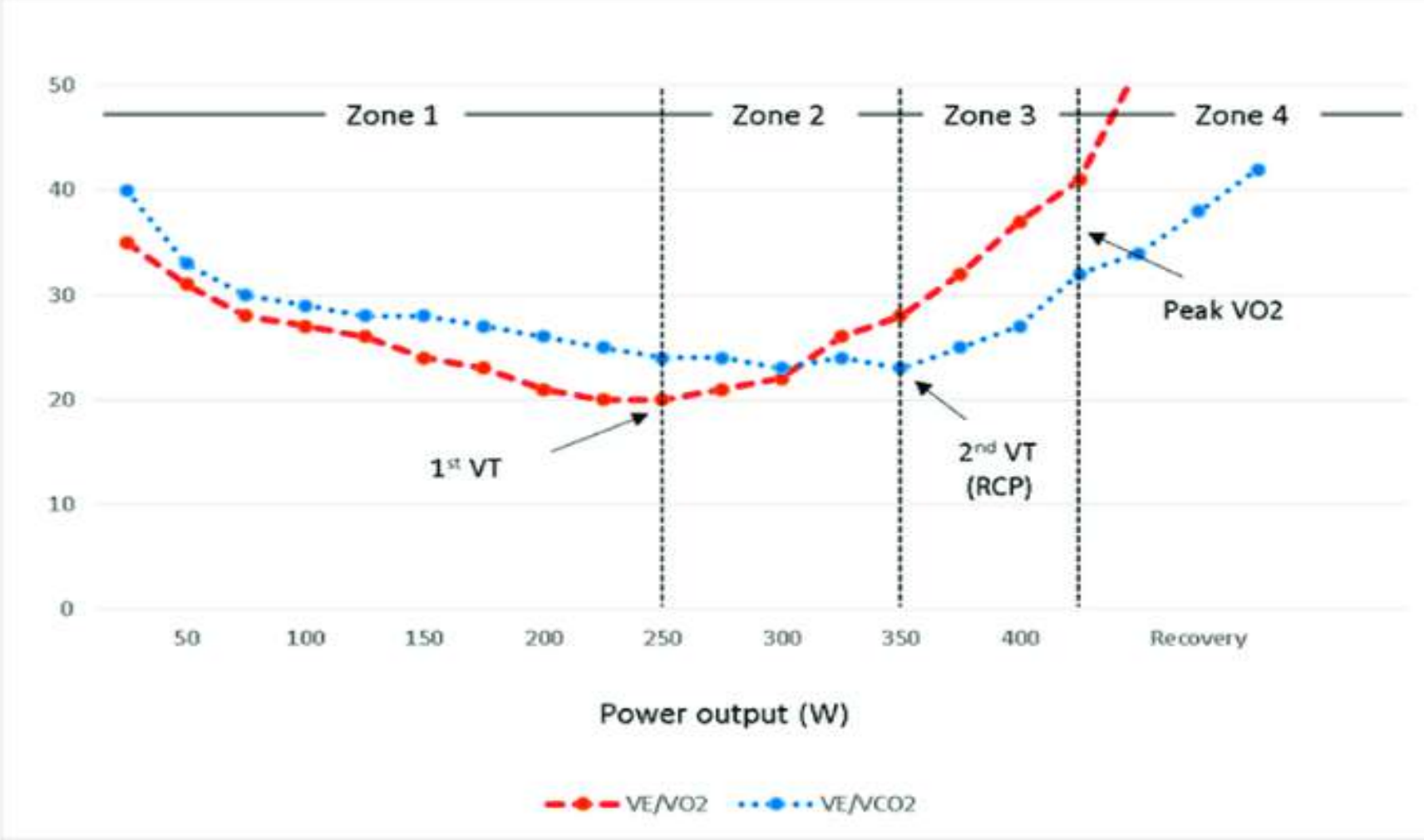
ATF üçün enerji mənbəyi



Aerob və anaerob metabolizm



https://clinicalgate.com/cardiopulmonary-response-to-exercise-in-health-and-disease/#s0020



The ventilatory equivalents for oxygen (VE/VO2) and carbon dioxide (VE/VCO2) and their association with first and second VT which form four training zones during an incremental CPET. VT: ventilatory threshold, RCP: respiratory compensation point.

doi: 10.1136/hrt.2007.121558

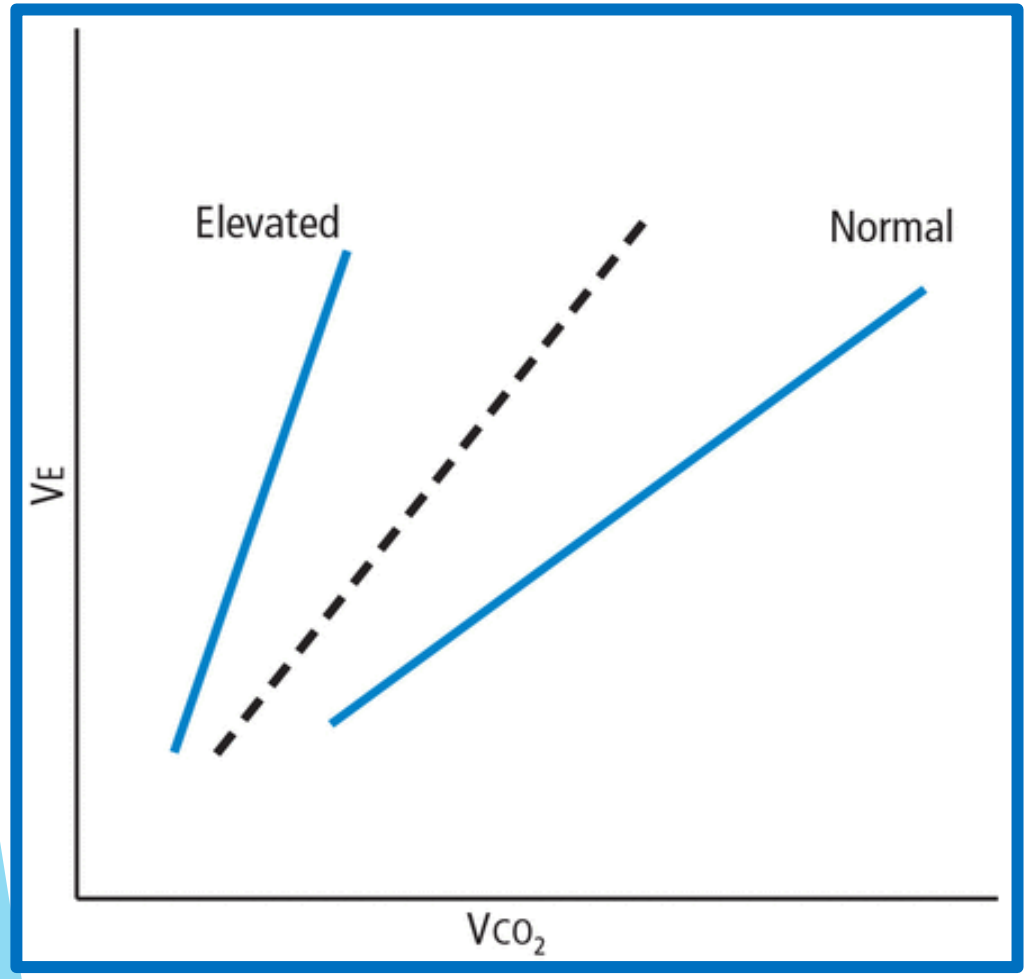
Testin nəticəsinə əsasən fərdi məşq zonaları müəyyən olunur

Zone		HR [/min]	v [km/h]	EE [kcal/h]
E:	Top	> 160	> 8.6	> 595
D:	Development	148 - 160	8.2 - 8.6	519 - 595
C:	Intensive Endurance	123 - 148	7.0 - 8.2	344 - 519
B:	Extensive Endurance	122 - 123	6.4 - 7.0	246 - 344
A:	Compensation	< 122	< 6.4	< 246

Please adapt the above given heart rate values to the sport activity being performed by adding or subtracting the following beats per minute:

-10 for Cycling, -5 for Walking, -20 for Swimming.

VE/VCO2 slope (mailliyi)



- **Ventilyasiya həcmi / CO2 xaric olunması (l/dəq)**
- **Ventilyasiyanın effektivliyini əks etdirir**
- **Normada 25-30 l/dəq – 1 litr CO2 üçün**
- **Göstəricinin artması ventilyasiyanın səmərəsizliyini (ventilyasiya-perfuziya uyğunsuzluğunu) əks etdirir**

- **≥34 l/dəq klinik cəhətdən əhəmiyyətli hemodinamik ürək-ağciyər xəstəliyini (ürək çatışmazlığı, ağciyər hipertenziyası, AXOX) göstərir**

- **ÜVS pik göstəricisi (Peak HR) - pHR ümumiyyətlə proqnozlaşdırılandan ≥ 85% - əlverişli hesab olunur - Yaşdan, fitness səviyyəsindən, BB- qəbulundan asılıdır - *Yükün tədricən artması ilə xətti olaraq artmalıdır***
- **Ehtiyat ÜVS (HRR) - Xronotrop aktivliyi əks etdirir**

(ÜVS max – sakitlik ÜVS) / (proqnozl. ÜVS max - sakitlik ÜVS),

Norma ≥ 80% beta-blokatorlarda olmadıqda; ≥ 62% BB-qəbulu zamanı. *Daha aşağı göstəricilər = xronotrop çatışmazlıq*

- **Heart rate recovery və ya ÜVS-nin bərpası (HRR):**

(ÜVS max) – (ÜVS bərpa dövrünün ilk dəqiqəsində)

HRR ≥ 12 normadır

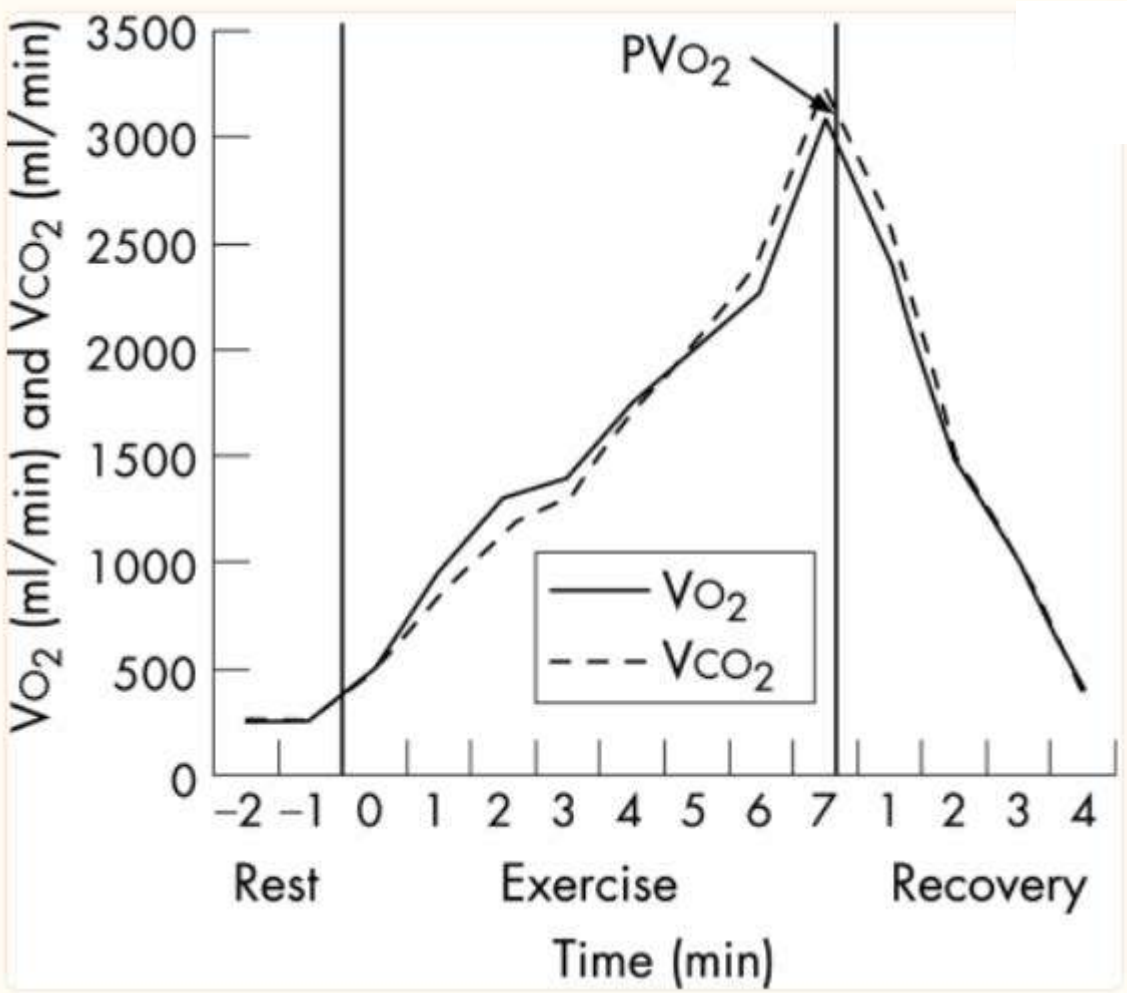
< 12-bütün populyasiyalar üçün anomal;

< 6 ÜÇ score sistemində sərhəd göstərici kimi qəbul olunur

- **VO2 / work slope - İş vahidi üçün oksigen istehlakı.**
- **Normal dəyər 10±1,5 ml/dəq/watt-dır.**
- **Veloerqometriya ilə təyin olunur; aşağı dəyərlər ürək çatışmazlığı və ya KAX zamanı anaerob yükün artmasını əks etdirir.**

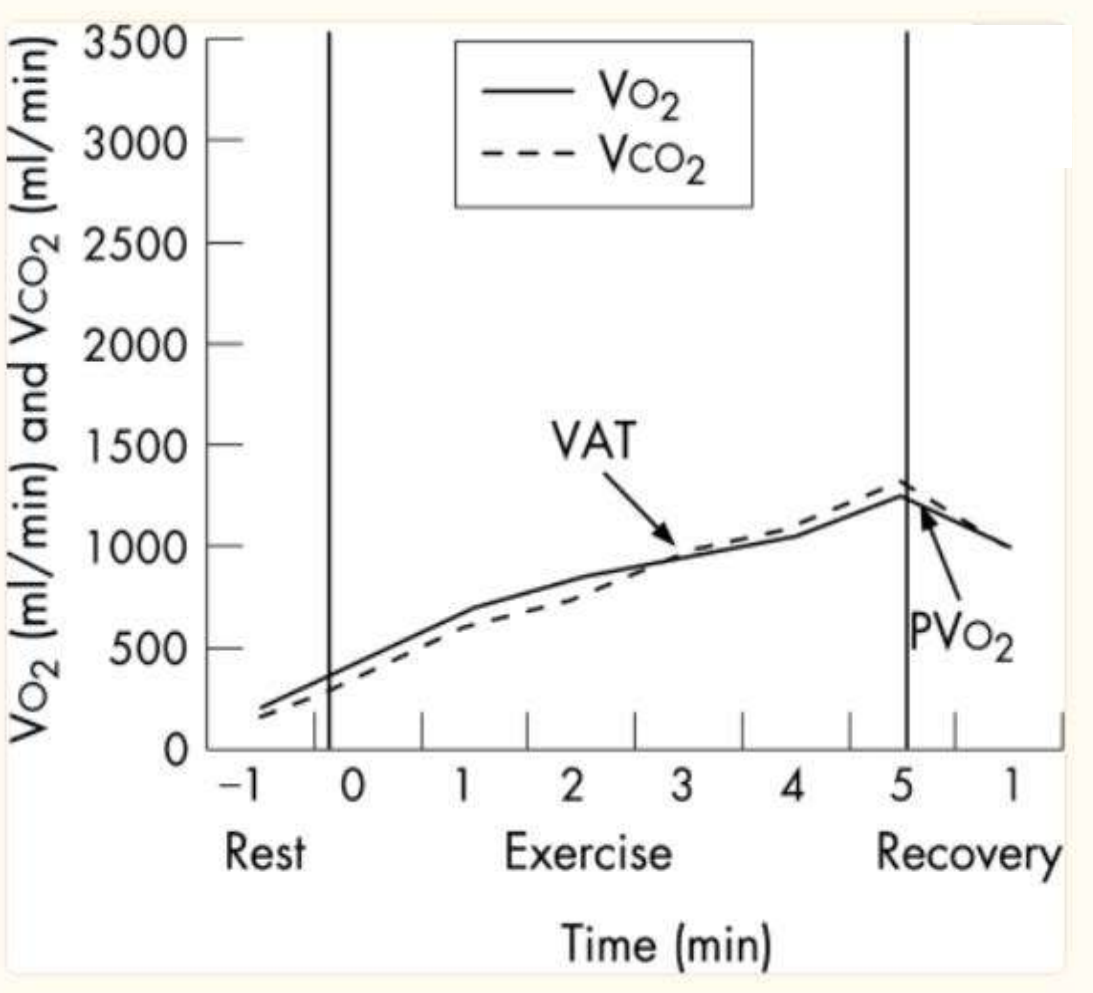
CPET-in vasitəsilə ÜÇ-nin ağırlıq dərəcəsi və proqnozunun qiymətləndirilməsi

CPET NƏTİCƏSİ - SAĞLAM 49-YAŞLI ŞƏXS, BRUCE PROTOKOLU



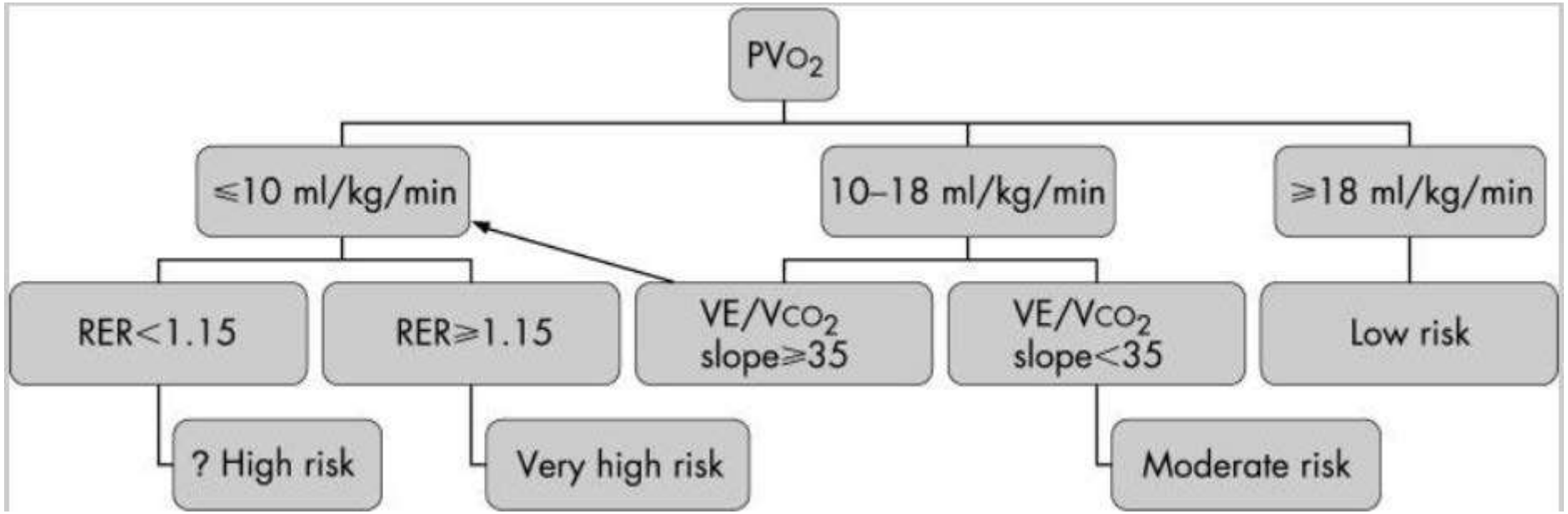
V_{O_2} -proqressiv xətti artma
Peak V_{O_2} (PV_{O_2}) = 3.09 l/min.

46-YAŞLI XÜÇ OLAN ŞƏXS, NYHA III FS, MODİFİKASİYA OLUNMUŞ BRUCE PROTOKOLU



PVo2 of 14 ml/kg/min (4 MET),
proqnozlaşdırılanın 42% (yaş, cins və çəkiyə görə)

A new prognostic algorithm that is structured on a multiparametric decoding scrutiny employing the stepwise introduction of PVO_2, VE/VCO_2 slope, and peak respiratory exchange ratio (RER).



The arrow indicates that patients with intermediate exercise capacity (ie, PVO_2 of >10 and <18 ml/kg/min) and excessive ventilatory response (ie, VE/VCO_2 slope of ⩾35) have a total mortality rate that is comparable to that detected with a PVO_2 of ⩽10 ml/kg/min (whole population). (Adapted from Corra and Mezzani[31].)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2000933/

MECKI Score: The Metabolic Exercise test data combined with Cardiac and Kidney Indexes

The MECKI Score is an anonymous tool for calculating the risk of chronic systolic heart failure, created using data obtained from a multicenter study based on over 2700 patients with an average follow up of more than 3 years. The tool is reserved exclusively for the clinical support of treating physicians.

The MECKI Score project is continuously evolving and the registry currently includes more than 7500 patients with an average follow up of more than 4 years. It constitutes a continuous source of data for scientific studies aimed at optimizing the study of the prognosis of patients with heart failure.

In order not to generate alarmism, it is recommended to patients who want to use it to perform the online test always with their own doctor, i.e. the general practitioner or the treating cardiologist, able to correctly interpret the result and its effects on therapies.

Centro Cardiologico Monzino is available to collaborate with the treating physician in the analysis of the MECKI Score results, by contacting

https://www.cardiologicomonzino.it/en/mecki-score/

Centro Cardiologico Monzino

Research for care

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EN IT

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PEAK VO_2 *(%PRED)*

15

VE/VCO_2 *(SLOPE)*

35

HEMOGLOBIN *(G/DL)*

12

NA_+ *(MMOL/L)*

135

LVEF *(%)*

35

MDRD *(ML/MIN)*

56

CALCULATE

23.00% risk of cardiovascular death or heart transplant within 2 years

CPET scoring system for patients with HF

Cardiopulmonary exercise testing scoring system for patients with heart failure

Variable	Value	Points
Ventilation/carbon dioxide (V_E/Vco_2) slope	≥ 34	7
Heart rate recovery[a]	≤ 6 bpm	5[b]
Oxygen uptake efficiency slope	≤ 1.4	2
Peak Vo_2	≤ 14 mL/kg/min	2

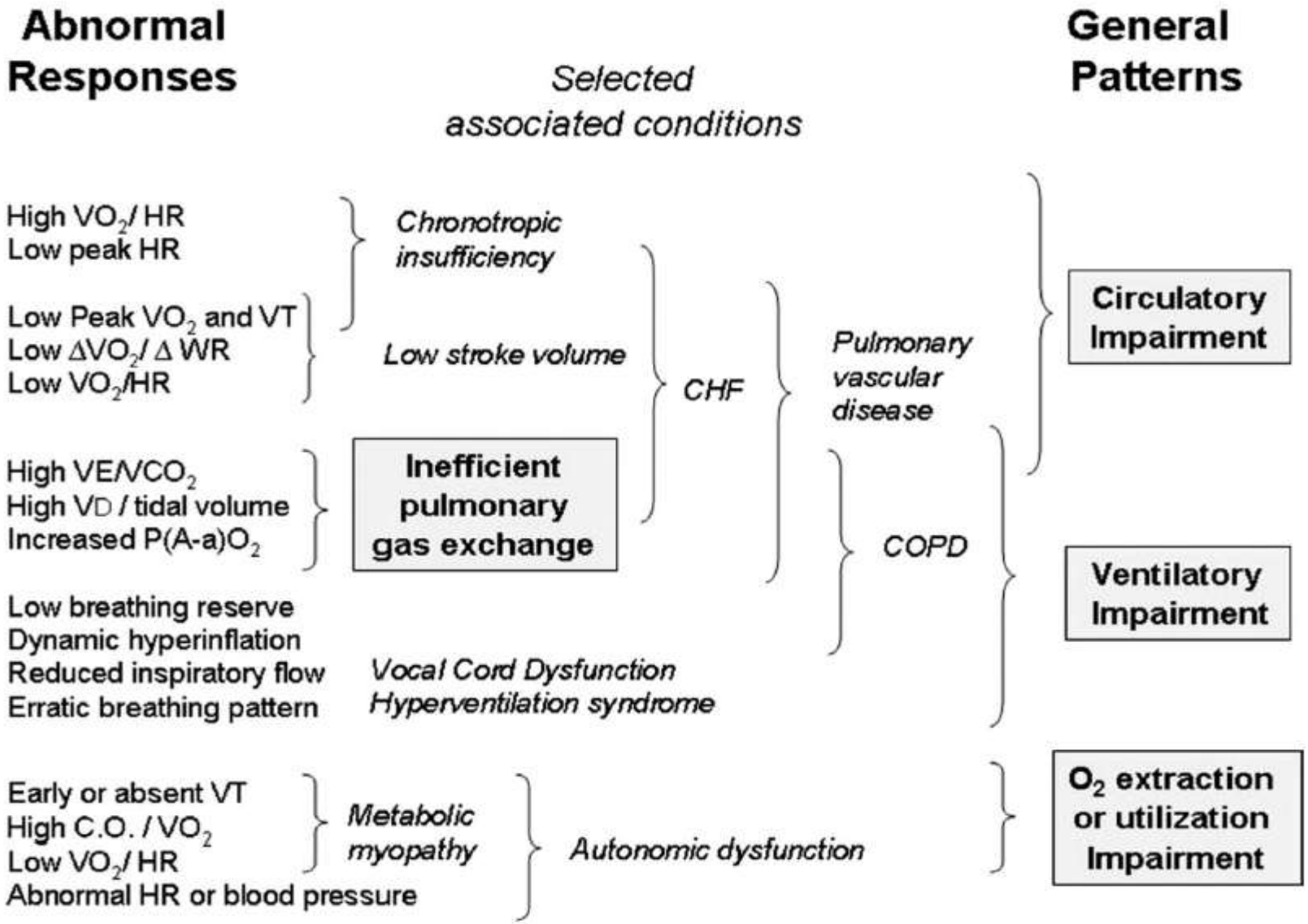
Score > 15 points: annual mortality rate 12.2%; relative risk > 9 for transplant, left ventricular assist device, or cardiac death.

Score < 5 points: annual mortality rate 1.2%.

a Maximum heart rate minus heart rate at 1 minute in recovery.

b 2 points if on a beta-blocker.

https://www.ccjm.org/content/84/2/161/tab-figures-data#ref-1



Balady G J et al. Circulation. 2010;122:191-225

American Heart Association.

Table 6 American Thoracic Society/American College of Chest Physicians: usual cardiopulmonary exercise response patterns

Measurement	Heart failure	COPD	ILD	Pulmonary vascular disease	Obesity	Deconditioned
PVo_2	↓	↓	↓	↓	↓ for actual, N for ideal weight	↓
VAT	↓	N / ↓/indeterminate	N or ↓	↓	N	N or ↓
Peak HR	Variable, N in mild	↓, N in mild	↓	N /slightly ↓	N /slightly ↓	N /slightly ↓
O_2 Pulse	↓	N or ↓	N or ↓	↓	N	↓
VE/MVV × 100	N or ↓	↑	N or ↑	N	N or ↑	N
VE/Vco_2 at VAT	↑	↑	↑	↑	N	N
VD/VAT	↑	↑	↑	↑	N	N
Pao_2	N	Variable	↓	↓	N/may ↑	N
$P(A–a)o_2$	Usually N	Variable, usually ↑	↑	↑	May ↓	N

EACPR/AHA Scientific Statement

Clinical Recommendations for Cardiopulmonary Exercise Testing Data Assessment in Specific Patient Populations

Appendix 2. Prognostic and Diagnostic Stratification for Patients With Heart Failure

Primary CPX variables

VE/V_{CO_2} slope	Peak V_{O_2}*	EOV	$P_{ET}CO_2$
Ventilatory class I VE/V_{CO_2} slope <30.0	Weber class A Peak V_{O_2} >20.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$	Not present	Resting $P_{ET}CO_2$ ≥33.0 mmHg 3–8 mmHg increase during ET
Ventilatory class II VE/V_{CO_2} slope 30.0–35.9	Weber class B Peak V_{O_2} = 16.0–20.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$		
Ventilatory class III VE/V_{CO_2} slope 36.0–44.9	Weber class C Peak V_{O_2} = 10.0–15.9 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$	Present	Resting $P_{ET}CO_2$ <33.0 mmHg <3 mmHg increase during exercise
Ventilatory class IV VE/V_{CO_2} slope ≥45.0	Weber class D Peak V_{O_2} <10.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$		

Standard ET variables

Haemodynamics	ECG	HRR
Rise in systolic BP during ET	No sustained arrhythmias, ectopic foci, and/or ST segment changes during ET and/or in recovery	>12 beats at 1 min recovery
Flat systolic BP response during exercise	Altered rhythm, ectopic foci, and or ST segment changes during ET and/or in recovery; did not lead to test termination	≤12 beats at 1 min recovery
Drop in systolic BP during ET	Altered rhythm, ectopic foci, and or ST segment changes during ET and/or in recovery; led to test termination	

Patient reason for test termination

Lower extremity muscle fatigue	Angina	Dyspnoea

Interpretation

- All variables in green: excellent prognosis in next 1–4 years (≥90% event free)
  - Maintain medical management and retest in 4 years.
- Greater number of CPX and standard ET variables in red/yellow/orange indicative of progressively worse prognosis.
  - All CPX variables in red: risk for major adverse event extremely high in next 1–4 years (>50%).
- Greater number of CPX and standard ET variables in red/yellow/orange indicative of increasing HF disease severity.
  - All CPX variables in red: expect significantly diminished cardiac output, elevated neurohormones, higher potential for secondary PH.
- Greater number of CPX and standard ET variables in red/yellow/orange warrants strong consideration of more aggressive medical management and surgical options.

(*Circulation*. 2012;126:2261-2274.)

- **End-tidal CO2 pressure – son tənəffüs CO2 təzyiqi**

- **Peak VO2**
- **VE/VCO2 slope**
- **EOV - exercise oscillatory ventilation – hyperpnea and hypopnea periodları ilə periodik tənəffüs**

CPET zamanı fiziki yükləmə üsulları: tredmil və ya veloerqometr?

Table 1 Exercise equipment: cycle ergometry vs treadmill

Variable	Cycle	Treadmill
Peak oxygen content (PVo_2)	Lower	Higher
Work rate measurement	Yes	No
Blood gas collection	Easier	More difficult
Noise and artefacts	Less	More
Safety	Safer	Less safe?
Weight bearing in obese subjects	Less	More
Degree of leg muscle training	Less	More
More appropriate for	Patients	Active normal subjects

Adapted from ATS/ACCP Statement on Cardiopulmonary Exercise Testing.[1]

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Article

Performance of Heart Failure Patients with Severely Reduced Ejection Fraction during Cardiopulmonary Exercise Testing on Treadmill and Cycle Ergometer; Similarities and Differences

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Abstract: Background: Peak oxygen consumption (VO_2) measured by cardiopulmonary exercise testing (CPET) is a significant predictor of mortality and future transplantation in heart failure patients with severely reduced ejection fraction (HFrEF). The present study evaluated the differences in peak VO_2 and other prognostic variables between treadmill and cycle CPETs in these patients. Methods: In this cross-over study design, thirty males with severe HFrEF underwent CPET on both a treadmill and a cycle ergometer within 2–5 days apart, and important CPET parameters between two exercise test modalities were compared. Results: Peak VO_2 was 23.12% higher on the treadmill than on cycle (20.55 ± 3.3 vs. 16.69 ± 3.01, $p < 0.001$, respectively). Minute ventilation to carbon dioxide production (VE/VCO_2) slope was not different between the two CPET modes ($p = 0.32$). There was a strong positive correlation between the VE/VCO_2 slopes during treadmill and cycle testing ($r = 0.79$; $p < 0.001$). VE/VCO_2 slope was not related to peak respiratory exchange ratio (RER) in either modality (treadmill, $r = 0.13$, $p = 0.48$; cycle, $r = 0.25$, $p = 0.17$). The RER level was significantly higher on the cycle ergometer ($p < 0.001$). Conclusion: Peak VO_2 is higher on treadmill than on cycle ergometer in severe HFrEF patients. In addition, VE/VCO_2 slope is not a modality dependent parameter and is not related to the patients' effort during CPET.

Keywords: cardiopulmonary exercise testing; heart failure; peak VO_2; treadmill; cycle ergometer; exercise test mode

check for updates

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HFrEF pasiyentlərdə tredmil test zamanı Peak VO2 veloerqometriya zamanı alınan nəticədən daha yüksəkdir.

VE/VCO2-slope göstəricisi metodikadan və pasiyentin sınaq zamanı göstərdiyi səydən asılı deyil.

Nəticə

- **CPET - orqanizmin fiziki iş qabiliyyətinin (exercise capacity) qiymətləndirilməsinin qızıl standartıdır**
- **HF xəstələrin diaqnostikasında, simptomlarının kəmiyyətcə qiymətləndirilməsində, riskin müəyyənləşdirilməsində, proqnoz və terapevtik müdaxilələrin müvəffəqiyyətinin qiymətləndirilməsində mühüm rol oynayır**
- **CPET göstəriciləri ilə hesablama şkalaları və alqoritmləri xəstəliyin ağırılıq dərəcəsinin və proqnozunun qiymətləndirilməsini asanlaşdırır**
- **CPET nəticələri qiymətləndirilərkən aşağıdakılar nəzərə alınmalıdır**

Veloerqometriya yerinə yetirilmiş yükün həcmini (work rate) birbaşa hesablamağa imkan verir.

Tredmil sınağı zamamı VO2-nin pik gəstəricisi veloserqometrindən daha yüksəkdir.