Cardiopulmonary exercise testing (CPX) for comprehensive cardiac evaluations

The role of CPX testing in the rehabilitation of cardiac patients.

Viviane M Conraads, MD, PhD
Department of Cardiology – Cardiac Rehabilitation Centre
Antwerp University Hospital – University of Antwerp, Belgium

NO DISCLOSURES
What do the guidelines say?

After myocardial revascularization (PCI, CABG)
Chronic Heart Failure
Guidelines on myocardial revascularization

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS)

Figure 4 Algorithm for prescription of functional evaluation at the onset of rehabilitation or exercise programme after percutaneous coronary intervention. The following general criteria should be considered in planning an exercise testing modality for exercise prescription: safety, i.e. stability of clinical, haemodynamic and rhythmic parameters, ischaemic and angina threshold (in the case of incomplete revascularization), degree of left ventricular ejection fraction impairment, associated factors (i.e. sedentary habits, orthopaedic limitations, occupational and recreational needs). *Upper limit for terminating submaximal 6-min single-stage (steady-state) exercise testing: rate of perceived exertion (Borg scale) 11–13/20 or maximal heart rate = heart rate at standing rest + 20–30 beats /min. Upper limit for terminating submaximal incremental testing: maximal heart rate = 70% heart rate reserve or 85% of age-predicted maximal heart rate. LVEF = left ventricular ejection fraction; PCI = percutaneous coronary intervention.
ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2012

The Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2012 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association (HFA) of the ESC
CPX; what is extra?

1. Diagnosis
   - Ischemia
   - Dyspnea – ex intolerance

2. Prognosis and guidance for treatment

3. Exercise prescription

4. Optimization of devices/patients with devices
"Ischemic Cascade"

Clinically recognized

Clinically silent

Normal function

Time/Magnitude Ischemia

Perfusion abnormalities

Diastolic dysfunction

Strain abnormalities

Systolic dysfunction

New ECG abnormalities

Ischemia
Which are the arguments pro-ischemia?

Fick formula:

\[ \text{VO}_2 = \text{cardiac output} \times \text{arteriovenous O}_2 \text{ difference} \]
\[ \text{VO}_2 = \text{SV} \times \text{Heart rate} \times \text{arteriovenous O}_2 \text{ difference} \]

\[ \text{O}_2 \text{ pulse (SV)} = \frac{\text{VO}_2}{\text{Heart rate}} \]
Contribution of cardiopulmonary indices in the assessment of patients with silent and symptomatic ischemia during exercise testing.

Table 1
Exercise test study

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group I (control)</th>
<th>Group II (silent ST depression)</th>
<th>Group III (symptomatic ST depression)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>51 ± 10.4</td>
<td>53.3 ± 9.5</td>
<td>60 ± 9.3</td>
</tr>
<tr>
<td>Max. heart rate (beats/min)</td>
<td>161.1 ± 21</td>
<td>154 ± 15.3</td>
<td>134.8 ± 15.2</td>
</tr>
<tr>
<td>%Max. predicted heart rate</td>
<td>94.75 ± 5.9</td>
<td>93 ± 7.9</td>
<td>88.4 ± 7.4</td>
</tr>
<tr>
<td>Heart rate of initial ischemia (beats/min)</td>
<td>130 ± 1.4</td>
<td>113 ± 10</td>
<td></td>
</tr>
<tr>
<td>Max. ST segment depression (mm) (V₄ - V₃)</td>
<td>-</td>
<td>2.52 ± 0.85</td>
<td>2.47 ± 0.69</td>
</tr>
<tr>
<td>Recovery from ischemia (min)</td>
<td>-</td>
<td>6.14 ± 4.6</td>
<td>9.43 ± 2.4</td>
</tr>
<tr>
<td>Mechanical load (W)</td>
<td>175 ± 44</td>
<td>167 ± 29</td>
<td>121 ± 33</td>
</tr>
</tbody>
</table>

Lower O₂pulse

<table>
<thead>
<tr>
<th>Group</th>
<th>VO₂-max (ml/min)</th>
<th>O₂-Pulse max</th>
<th>VAT (%)</th>
<th>VAT (ml/min)</th>
<th>LVEF-rest (%)</th>
<th>Δ LVEF (ex-r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>25.2 ± 6.3</td>
<td>15.7 ± 3.4</td>
<td>51.2 ± 6.6</td>
<td>1075 ± 289</td>
<td>54.7 ± 7</td>
<td>5.4 ± 4.85</td>
</tr>
<tr>
<td>II</td>
<td>22.4 ± 2.8</td>
<td>14.5 ± 2</td>
<td>47.0 ± 5.3</td>
<td>854 ± 136</td>
<td>52 ± 10</td>
<td>1.2 ± 6.7</td>
</tr>
<tr>
<td>III</td>
<td>16.0 ± 2.5</td>
<td>11.4 ± 2</td>
<td>41.6 ± 7.7</td>
<td>683 ± 105</td>
<td>51 ± 8.5</td>
<td>-5.87 ± 6.3</td>
</tr>
</tbody>
</table>

Flattening $\Delta O_2$ pulse and $\Delta VO_2/\Delta W$ trajectory

**Fig. 2** An example of $O_2$ pulse (a) and $\Delta VO_2/\Delta$ work rate (b) slope in two representative patients. One had a negative ECG stress testing and a negative scan (closed circles). The other developed myocardial ischaemia during exercise, and also had a reversible myocardial defect on scintigraphy (SDS 14, SSS 15) (open circles). The dotted line indicates the onset of flattening in both $O_2$ pulse and $VO_2$ as related to work rate increase, evident only in the patient with a positive scan. Note the absence of flattening in both $O_2$ pulse and $VO_2$ as related to work rate in the patient who had no ST segment changes during exercise and a negative scan. In (b), the slope above the inflection point is flattened as compared with the slope from start to the inflection point (3.5 ml/min/W vs 9.1 ml/min/W). For details, see text. (a) Time to $O_2$ pulse flattening; (b) $O_2$ pulse flattening duration.

Fig. 4 Temporal changes in ST segment depression (dotted line) and oxygen uptake (filled line) in 52 patients with a positive ECG stress test and a reversible myocardial defect on myocardial scintigraphy. A flattening in oxygen uptake was evident much earlier (265 ± 33 s) than ST depression. Note that ventilation continues to rise with work rate increase independently from oxygen uptake. For details, see text.
Diagnosis

MVV: maximal voluntary ventilation during 1 min = $FEV_1 \times 35$
**55 yr-old man**

**Peak VO\textsubscript{2} predicted = 32.5ml/kg/min**

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<tbody>
<tr>
<td>0:00:10</td>
<td>0</td>
<td>89</td>
<td>7.0</td>
<td>4.4</td>
<td>12</td>
<td>35,5</td>
<td>16</td>
<td>25</td>
<td>0.63</td>
<td>7.1</td>
<td>0.34</td>
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<tr>
<td>0:00:20</td>
<td>0</td>
<td>90</td>
<td>10.2</td>
<td>6.8</td>
<td>17</td>
<td>41.9</td>
<td>16</td>
<td>24</td>
<td>0.67</td>
<td>10.2</td>
<td>0.41</td>
</tr>
<tr>
<td>0:00:30</td>
<td>0</td>
<td>89</td>
<td>8.9</td>
<td>6.2</td>
<td>16</td>
<td>44.3</td>
<td>18</td>
<td>25</td>
<td>0.70</td>
<td>9.0</td>
<td>0.37</td>
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<tr>
<td>0:00:40</td>
<td>83</td>
<td>89</td>
<td>8.2</td>
<td>6.8</td>
<td>16</td>
<td>43.6</td>
<td>18</td>
<td>26</td>
<td>0.71</td>
<td>8.4</td>
<td>0.36</td>
</tr>
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**MVV = FEV\textsubscript{1} \times 35 = 2 \ l \times 35 = 70l/min**

Breathing reserve = 0%
CPX; what is extra?

1. Diagnosis

2. Prognosis and guidance for R/Prognostic parameters CRT – VAD – HTX

3. Exercise prescription

4. Optimization of devices/patients with devices
Prognostic parameters

CPX variables Ischemia

• % predicted VO$_2$
• ΔO$_2$/ΔW trajectory
• ΔVO$_2$/ΔW trajectory

• Systolic Bloodpressure
• ECG abnormalities
Prognostic parameters

CPX variables CHF

- peakVO₂
- VE/VCO₂ slope
- Oscillatory breathing
- PETCO₂
- HRRecovery
- OUES
- Circulatory power
- VO₂t1/2

- Systolic Bloodpressure
- ECG abnormalities
CPX; what is extra?

1. Diagnosis

2. Prognosis and guidance for R/

3. Exercise prescription
   - Safety
   - Efficacy

4. Optimization of devices/patients with devices

Training Heart Rate (THR) = HR at x% VO\textsubscript{2peak}
Moderate continuous training

Higher intensity training

High intensity aerobic interval training

High intensity anaerobic interval training

Ventilation

CO\textsubscript{2} production

VO\textsubscript{2} (ml/kg/min)
Exercise intensity

Rest | Exercise

Arbitrary units

Ventilation

CO₂ production

VAT

RCP

VO₂ (ml/kg/min)

Peak HR

RCP

VO₂ plateau

RER > 1.05-1.1

Conraads VM & Beckers PJ. Heart 2010;96:2025
Exercise intensity

Conraads VM & Beckers PJ. Heart 2010;96:2025
CPX; what is extra?

1. Diagnosis

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Fig. 1

![Evolution of peak heart rate during cardiopulmonary exercise test 1 and cardiopulmonary exercise test 2.](image1)

Fig. 3

![Evolution of oxygen uptake (VO2) peak during cardiopulmonary exercise test 1 and cardiopulmonary exercise test 2.](image2)

![Graph showing the evolution of Vo2max](image)

**Fig. 2**

Evolution of Vo2max for the CRT+ (pharmacological therapy plus exercise training programme; ●) and CRT− (pharmacological therapy only; □) groups.
CPX; just do it?
Safety of symptom limited cardiopulmonary exercise testing in patients with chronic heart failure due to severe left ventricular systolic dysfunction.

N=4411 CPET

40% ICD (932)

293 ICDs fired once
688 discharges/2.5yr

no deaths
no HF exacerbation requiring hospital.
no angina requiring hospital.
no MI
no sustained VT
no stroke or TIA

1 VFib - next day
1 Sust. VTach - next day
No ex-related discharge

27 tests stopped because 3-5 beats SVT or VT runs
Precautions: 5-10 beats below treatment zone, deactivate ICD or increase ventricular discharge rate
CPX & rehabilitation: conclusions

1. Provides information (far) beyond “classical” exercise testing

2. Is feasible and safe even in high risk/debilitated patients

3. Useful to optimize therapy and exercise prescription

4. Requires equipment/time/expertise/money