Cardiopulmonary Exercise Testing in Sports Cardiology

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Abstract

Leisure-time and elite athletes often seek sports medical advice for inadequate exertional dyspnea and loss of performance. The work-up has to rule-out underlying cardiac pathologies that are associated with sudden cardiac death, although commonly the symptoms are training- and not disease-related. Cardiopulmonary exercise testing (CPET) helps to differentiate between cardiac and pulmonary causes and guides further diagnostic and therapy. This article illustrates the potential of CPET in three clinical cases.

Keywords: Performance, dyspnea, peak oxygen uptake, athlete

Zusammenfassung

Freizeit- und Spitzensportler suchen bei inadäquater Belastungsdyspnoe und Leistungsminderung oft sportmedizinischen Rat. Die Abklärung muss zugrundeliegende Herzerkrankungen, die mit dem plötzlichen Herztod assoziiert sind, ausschliessen, obwohl die Symptome häufig trainings- und nicht krankheitsbedingt sind. Die spiroergometrische Leistungsdiagnostik (CPET) hilft, zwischen kardialen und pulmonalen Ursachen zu unterscheiden und steuert die weitere Diagnostik und Therapie. Dieser Artikel veranschaulicht das Potenzial der CPET in drei klinischen Fällen.

Leistungsfähigkeit, Dyspnoe, maximale Sauerstoffaufnahme, Athlet

Introduction

Cardiopulmonary exercise testing (CPET) is a well established assessment technique to 1) accurately quantify cardiorespiratory fitness, 2) identify exercise-limiting pathophysiological mechanisms and/or performance differences, and 3) formulate function-based prognostic stratifications [1]. Despite evidence-based CPET indications and algorithms for a number of clinical conditions *(Table)* it is widely underused in clinical practice [2].

Unexplained exertional dyspnea and loss of performance are common symptoms why leisure-time and elite athletes are referred to dedicated sports cardiology clinics [3]. This case-based article intends to illustrate the potential of CPET in the evaluation of these athletes.

Unexplained exertional dyspnea
Unexplained fatigue and/or reduced performance
Chronic obstructive pulmonary disease
Interstitial lung disease
Pulmonary arterial hypertension (pre- and post-capillary)
Heart failure with reduced or preserved ejection fraction
Congenital heart disease
Hypertrophic cardiomyopathy
Valvular heart disease/dysfunction
Coronary artery disease/suspected myocardial ischaemia
Pre- and post surgical risk assessment
Pre- and post cardiac or pulmonary rehabilitation
Assessment of apparently healthy individuals (research tool)

Table: CPET recommendations for specific populations [adopted from 1, 2]

Basic exercise physiology

The response to exercise involves most organs of the body (especially nervous, pulmonary, locomotor and cardiovascular systems). Chronic exercise gives rise to dose-dependent adaptations resulting in the remodeling of the involved organs (structure, function) [4]. In particular, it is associated with a higher plasma and red blood cell volume for an improved transport of O_2 and CO_2 [5].

The majority of exercise effects are related to providing sufficient oxygen supply to the involved working muscles. At rest, the oxygen uptake is approximately 3.5 ml/min/kg (one metabolic equivalent, MET) [6]. In untrained individuals, maximum oxygen uptake can increase 10- to 12-fold. In highly trained athletes, maximum oxygen uptake can increase >20-fold (to more than 6 L/min or 80 ml/min/kg) [7].

The Fick equation "Cardiac output (CO, Q_c) is oxygen consumption (V_{O2}) divided by the difference in the oxygen content (C_{O2}) of arterial and mixed venous blood (a–$\bar{v}$)" illustrates the significance of cardiac output for the maximal oxygen uptake. Both heart rate *(HR)* and stroke volume *(SV)* contribute to the increase of the cardiac output:

- $\dot{Q}_C = \frac{\dot{V}_{O_2}}{C_{a-\bar{v}O_2}}$
- $\dot{V}_{O_2} = \dot{Q}_C \times C_{a-\bar{v}O_2}$
- $\dot{V}_{O_2} = SV \times HR \times C_{a-\bar{v}O_2}$

At rest, CO is ca. 5 L/min. Athletes have larger ventricular cavities and generate a greater SV, and their resting HR is lower. Increase of HR during exercise is responsible for the majority of cardiac output augmentation. The autonomic nervous system is responsible for the transition from rest to exercise for a rapid matching of oxygen supply to metabolic demand. The initial parasympathetic withdrawal is followed by sympathetic and neurohumoral activation. Maximal HR varies among individuals, decreases with age, and does not significantly increase with exercise training. On the other hand, SV may increase significantly with prolonged exercise training [8].

In untrained individuals, CO can increase 4- to 5-fold to 20–25 L/min under exercise. In highly trained athletes, CO can increase 6- to 8-fold to 30–40 L/min [9].

During intense exercise, the limiting factor for maximum oxygen uptake is the capability of the heart to deliver O_2, not the muscle to consume it. Vascular conductance and blood pressure are adjusted to match oxygen supply with tissue oxygen demand [10,11].

At high exercise intensities, where the metabolic acidosis has to be respiratorily compensated, the circulatory system can no longer meet the demands of locomotor and intercostal muscles. This gives rise to a diminished vascular conductance and intercostal muscle blood flow in favor of the locomotor muscles. This mismatch may contribute to respiratory muscle fatigue [12].

Case 1

A 61-year-old former track-and-field athlete and marathon runner presented with progredient dyspnoe on exertion and loss of performance during his exercise training. He had a history of coronary artery bypass graft (CABG) surgery after a non-ST segment elevation myocardial infarction (NSTEMI) with a preserved ejection fraction (EF 60%). His cardiovascular risk factors were arterial hypertension and dyslipidemia, but no diabetes mellitus.

Work-up

Resting spirometry showed no relevant restriction or obstruction. Resting electrocardiogram (ECG) and echocardiography were normal. A CPET on a cycle ergometer was performed. The test showed a reduced cardiorespiratory fitness (VO_2 peak 78% of predicted). Dyspnoe on exertion, but no angina pectoris was reproduced during the exercise test. The ECG showed no signs of myocardial ischemia.

CPET interpretation and follow-up

The Wasserman 9-Panel Plot is shown in Figure 1. Panel 7 demonstrates a normal pattern of respiration and no signs of respiratory limitation. In panel 2 the O_2 pulse trajectory (surrogate for the left ventricular stroke volume) showed an ear-

ly plateau followed by a decline. In panel 3 the $\Delta VO_2/\Delta W$ trajectory (surrogate for left ventricular cardiac output) showed a flattening at the end of the test. These patterns are indicative of myocardial ischemia [1]. The patient underwent coronary angiography which confirmed a significant stenosis of the left anterior descending artery (LAD) after the bypass anastomosis. A percutaneous coronary intervention (PCI) with stent implantation was performed *(Figure 2)*. Afterwards the patients was free from symptoms. The post-PCI CPET showed an improved exercise capacity and a normalization of O_2 pulse trajectory and $\Delta VO_2/\Delta W$ trajectory *(Figure 3)*.

Case 1 discussion

CPET helped to rule out an underlying pulmonary cause for the exertional dyspnea. It guided the diagnostic strategy towards an invasive procedure despite a normal exercise ECG. CPET has been shown to have a better diagnostic and predictive accuracy than traditional exercise testing to detect or exclude myocardial ischemia [13].

Case 2

A 25 year old female leisure-time runner presented with dyspnea and chest discomfort on exertion. She has had allergic asthma since onset of adolescence and was treated with an inhaled glucocorticoid as well as a long-acting beta-2 sympathomimetic drug. Otherwise she was healthy and non-smoking. There was no known family history of cardiac diseases. At the time of presentation, she did not suffer from a pulmonary infection.

Work-up

Resting spirometry showed a decrease of forced expiratory volume in one second (FEV1 2.86 l, 75% of predicted) as well as a low Tiffeneau-Pinelli index (60%) *(Figure 4)* compatible with her known obstructive disease.
The resting ECG was normal. A CPET on a cycle ergometer with flow-volume loops during exercise was performed. The test showed a normal cardiorespiratory fitness (VO_2 peak 118% of predicted). Dyspnea on exertion and chest discomfort could be reproduced during the exercise test. The ECG showed no signs of myocardial ischemia.

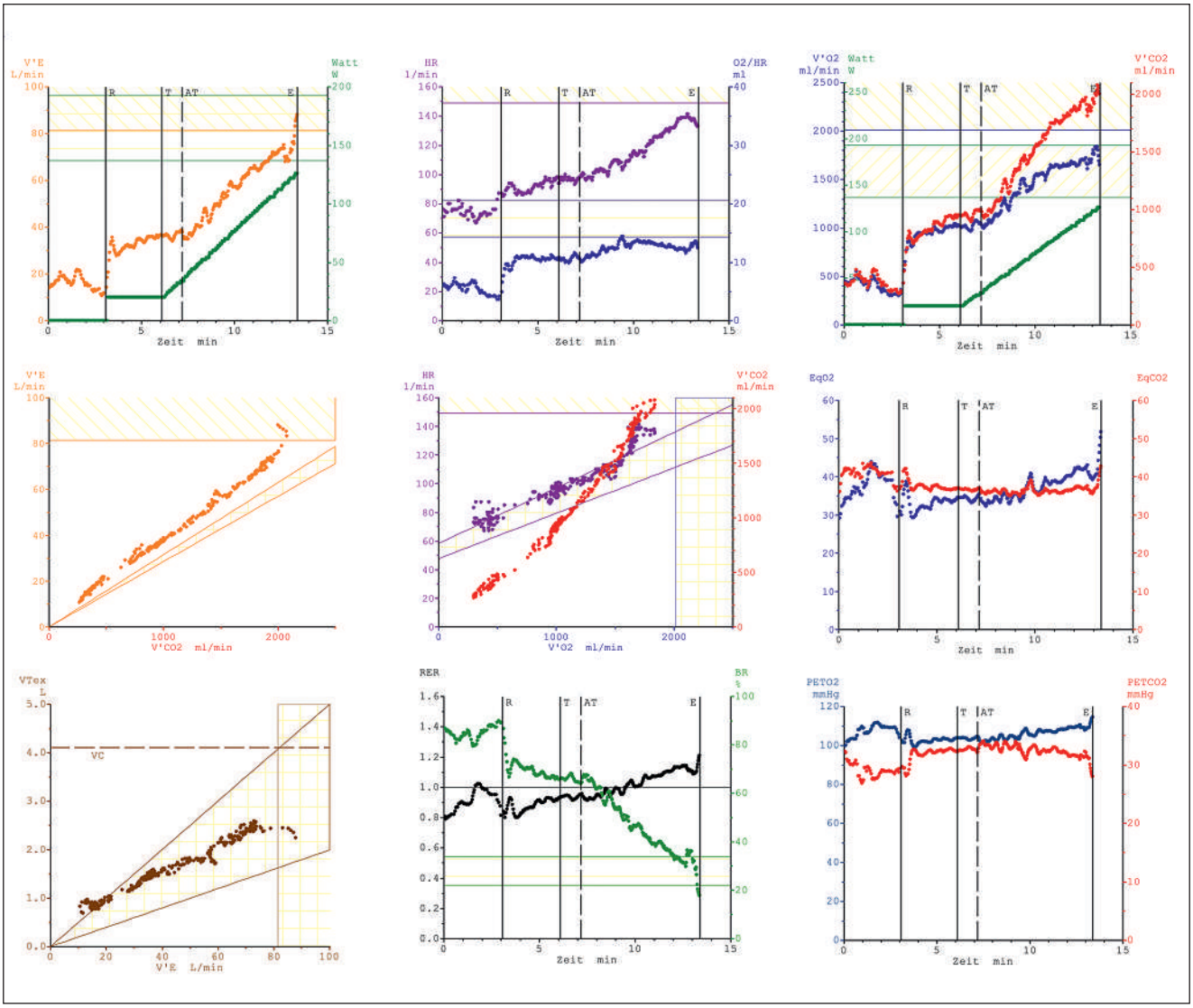

Figure 1: Case 1. Wasserman 9-Panel Plot

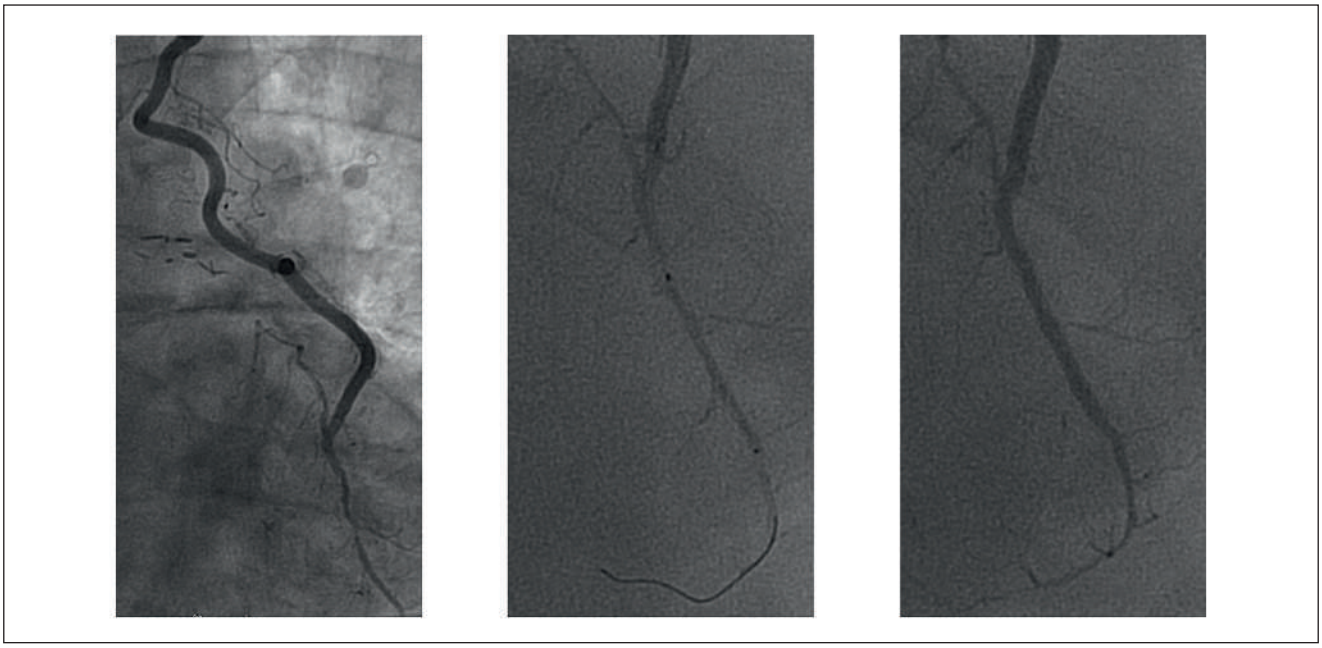

Figure 2: Case 1. Coronary angiography and PCI. Left panel: significant stenosis of the LAD after the bypass anastomosis. Middle panel: PCI LAD. Right panel: LAD without residual stenosis and good perfusion of the apical myocardium.

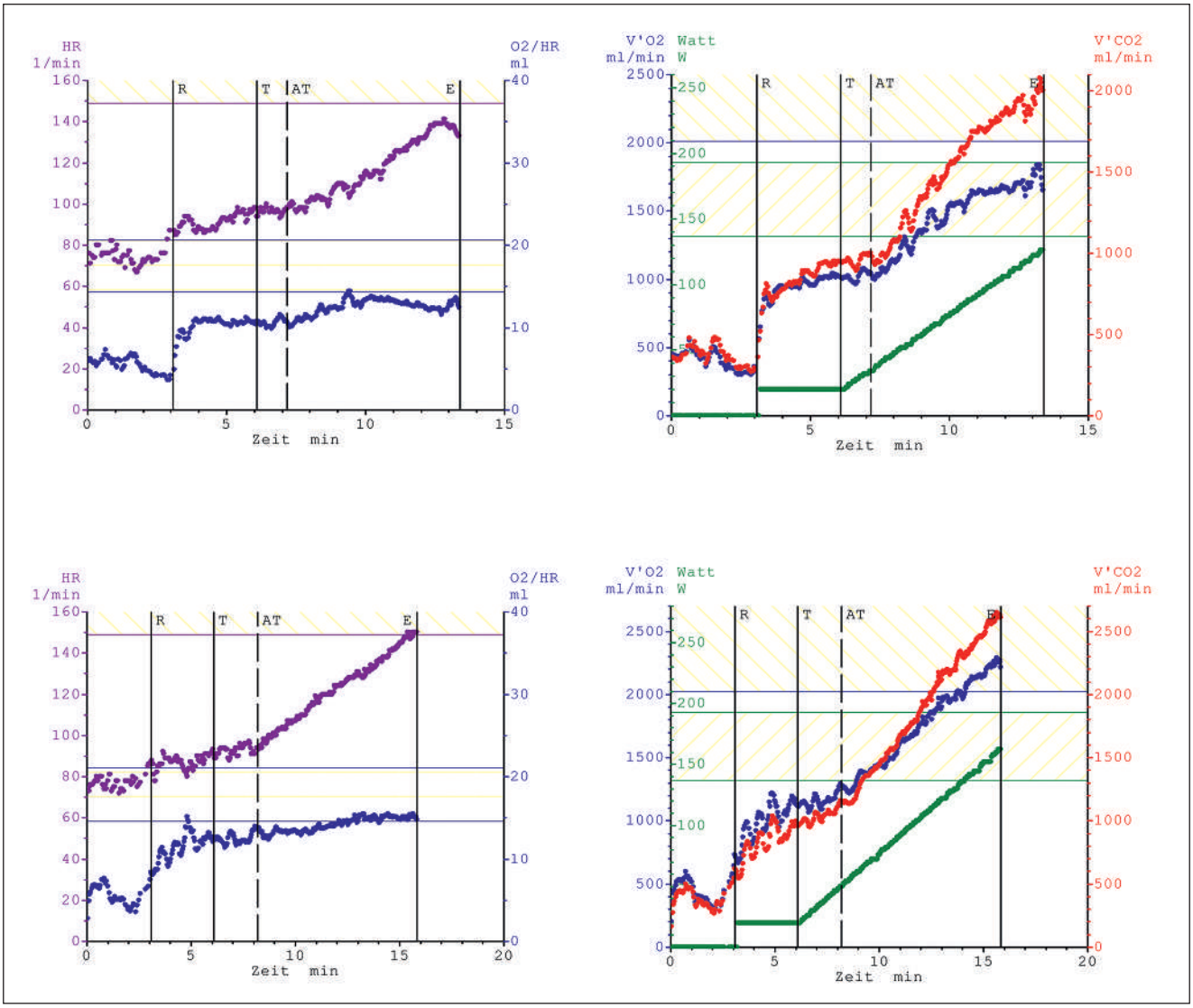

Figure 3: Case 1. O_2 pulse trajectory and ΔVO2/ΔW trajectory before (upper row) and after (lower row) PCI.

CPET interpretation

The Wasserman 9-Panel Plot is shown in Figure 5. Panel 7 demonstrates an abnormal respiratory pattern. After a normal increase of the tidal volume (VTex) to 60% of the vital capacity (VC), the patient's VTex decreased and she developed tachypnea (>50 breath/min). Breathing reserve (BR, ventilation (VE)/predicted maximum voluntary VE) became negative at the end of the testing period (Panel 8). Hyperventilation led to a ventilation/perfusion mismatch, seen as an abnormal high VE/VCO_2 slope (Panel 4). Normal cardiac hemodynamics are shown in panel 2 (O_2 pulse trajectory) and 3 ($\Delta VO_2/\Delta W$ trajectory). This pattern is indicative for dynamic hyperinflation under exertion. The flow-volume loops *(Figure 6)* confirmed the diagnosis by demonstrating an expiratory flow limitation and an increase instead of a decrease of the end-expiratory lung volume (EELV).

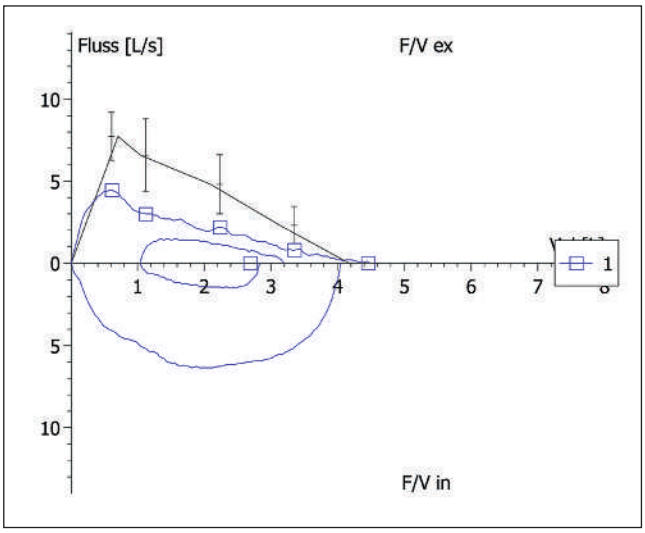

Figure 4: Case 2. Pre-test resting spirometry

Case 2 discussion

CPET helped to rule out myocardial ischemia as underling cause of the chest discomfort (e.g. coronary anomaly in young individuals). It confirmed a pulmonary limitation with expiratory flow limitation and dynamic hyperinflation in the presence of a sub-optimal treated bronchial asthma. It helped to guide therapy (recommendation of a short-acting beta-2 sympathomimetic drug prior to exercise). Flow-volume loops during exercise are useful in the differentiation of unexplained exertional dyspnea [2].

Case 3

A 39-year old male ambitious amateur athlete presented with progredient exertional dyspnea, loss of performance and an inadequate slow increase in heart rate during exercise for the previous 6 months. He practiced endurance sport (running, cycling, and swimming) since he was 18 years old with a weekly volume of 10 to 25 hours and participated in several long-distance competitions. He had no history of medical diseases and had no cardiovascular risk factors.

Work-up

Resting spirometry showed no relevant restriction or obstruction. Resting ECG was normal. Echocardiography showed a normal systolic and diastolic function and enlargement of all cavities, compatible with an athlete's heart. A CPET on a cycle ergometer was performed. The test showed an above-average cardiorespiratory fitness (VO_2 peak 125% of predicted). Dyspnea on exertion and fatigue, but no angina pectoris was reported at the end of the exercise test. The ECG showed no signs of myocardial ischemia.

CPET interpretation

The Wasserman 9-Panel Plot is shown in figure 7. The test does not show relevant pulmonary or cardiac limitations. In the presence of an above-average exercise performance, a depleted BR is not an unusual finding. The slight decrease of VTex prior to peak exercise could be interpreted as beginning respiratory fatigue. The test confirmed a relatively low heart rate during exercise (panel 5). However, together with the above-average O_2 pulse trajectory (panel 2), this finding is compatible with an athlete's heart.

Case 3 discussion

The only slightly above-average performance did not match with the extraordinary exercise training history. An exercise capacity exceeding normal reference values may be abnormally low for an athlete. The CPET triggered a full medical work-up including a blood count. Pancytopenia was detected (hemoglobin 92 g/L, leucocytes 0.86 G/L, erythrocytes 2.63 T/L, thrombocytes 42 G/L). The patient was immediately transferred to hematooncology. Acute myeloid leukemia was diagnosed and treatment was initiated the next day.

Summary

1. Unexplained exertional dyspnea and loss of performance are common complaints in athletes and can be related to pulmonary, cardiac, and other medical conditions. The use of CPET helps to distinguish between these entities and has been endorsed for this indication in recent scientific statements [1,2].
2. However, it is of great importance to understand that prior to CPET a thorough history taking, clinical examination and basic blood exam are essential. CPET may then provide further guidance for the final diagnosis.
3. To better recognize and differentiate pulmonary pathologies lung function testing immediately before and after CPET is recommended.
4. For athletic individuals, normal values have to be put in the context of the athlete's exercise training history. "Just normal CPET values" in highly trained individuals may hide a medical pathology.

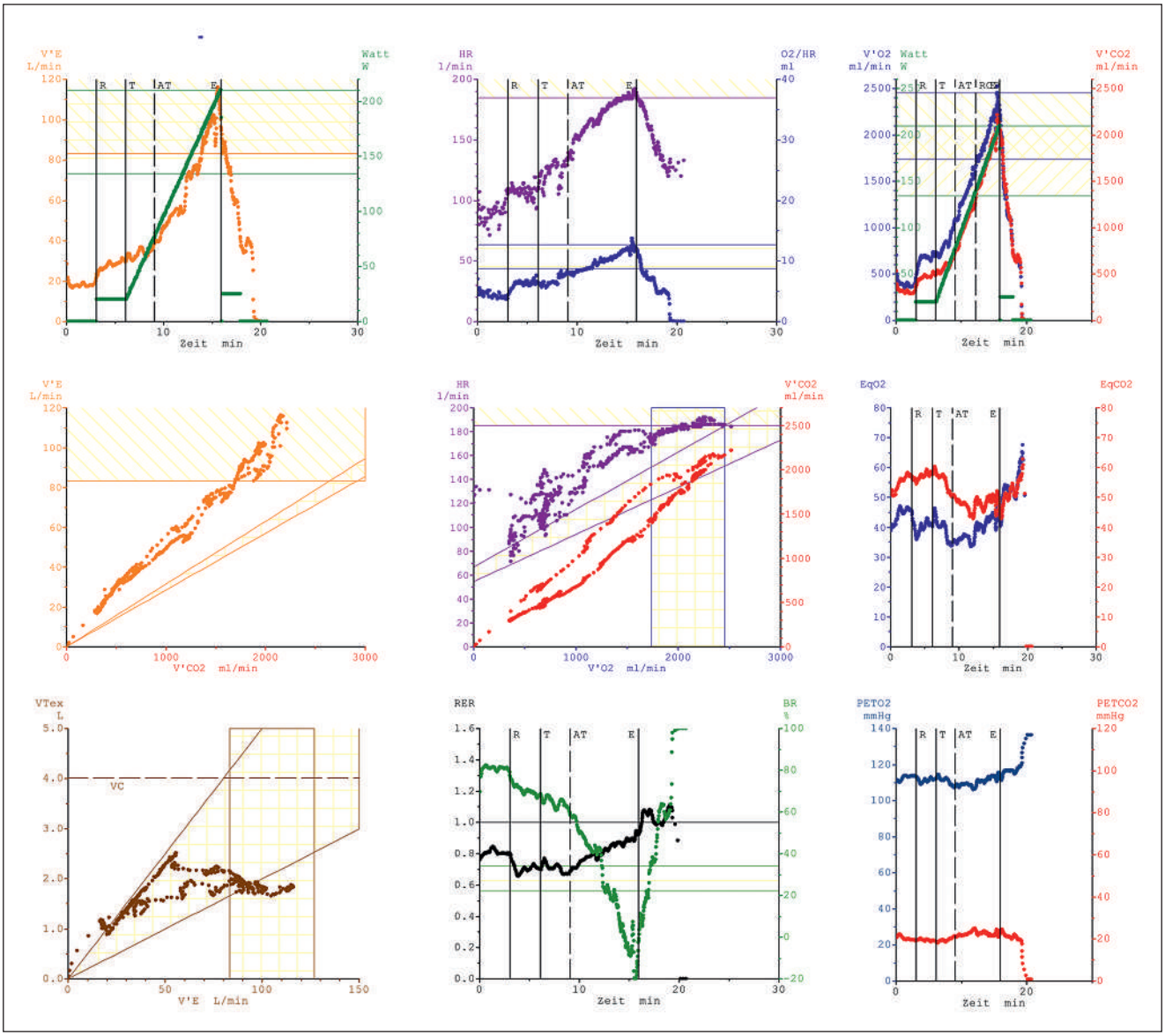

Figure 5: Case 2. Wasserman 9-Panel Plot

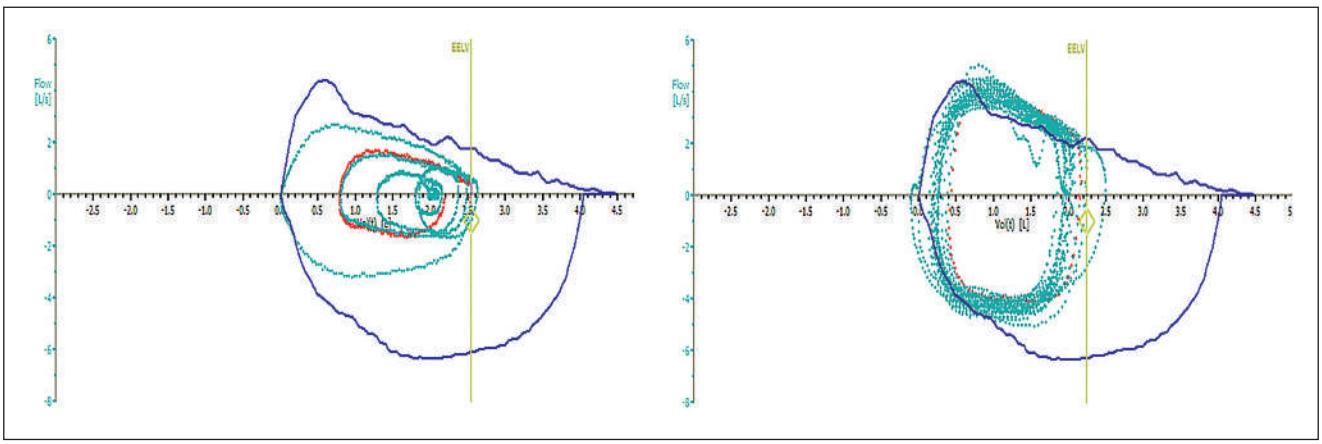

Figure 6: Case 2. Flow-volume loops.
Left panel: Flow-volume loops during warm-up phase. Right panel: Flow-volume loops at peak exercise

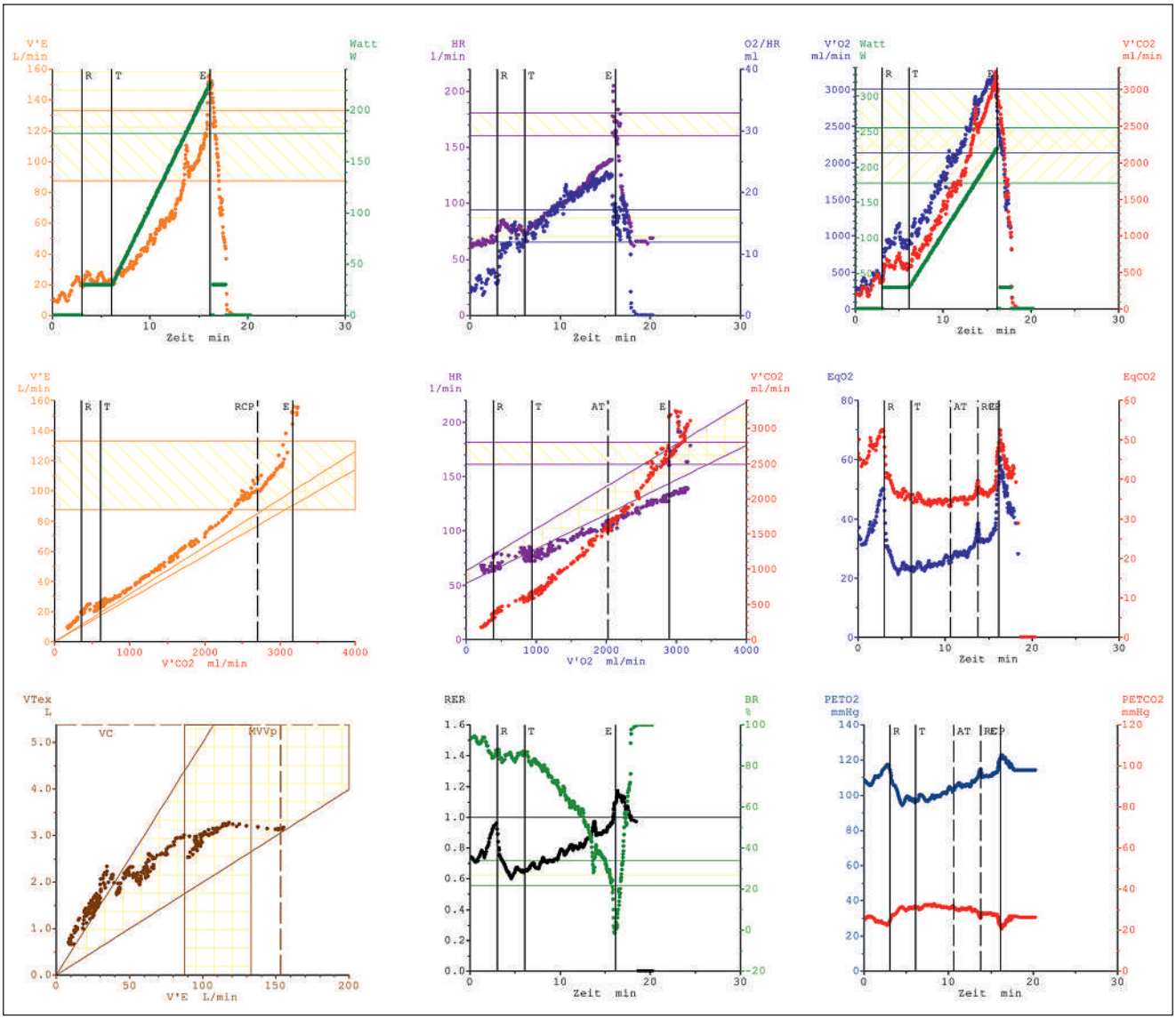

Figure 7: Case 3. Wasserman 9-Panel Plot

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