

The Role of Cardiopulmonary Exercise Testing in Exercise Prescription Design for Chronic Non-communicable Diseases

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Abstract: *Insufficient physical activity levels, combined with high-energy dietary intake and sedentary lifestyles, have become the leading independent risk factors for the development of chronic non-communicable diseases (NCDs). This review systematically elaborates on the central role of cardiopulmonary exercise testing (CPET) in exercise prescription design for NCD populations, establishes a precise exercise prescription formulation process based on CPET core indicators, and provides evidence-based support for exercise rehabilitation practice in chronic disease populations. The results indicate that CPET provides objective, precise, and individualized exercise prescription formulation basis for chronic disease populations through accurate measurement of core indicators such as peak oxygen uptake (VO_{2peak}), anaerobic threshold (AT), and ventilatory efficiency (VE/VCO₂ slope). Exercise prescriptions based on CPET results can significantly improve functional status and clinical prognosis in patients with chronic diseases such as cardiovascular diseases, type 2 diabetes mellitus, and chronic obstructive pulmonary disease. It is recommended that CPET be adopted as a routine assessment tool for exercise rehabilitation in chronic disease populations, promoting the transformation of exercise prescriptions from “empirical” to “precision-based” approaches.*

Keywords: Cardiopulmonary exercise testing, Chronic non-communicable diseases, Exercise prescription, Anaerobic threshold, Precision medicine, Exercise rehabilitation.

1. Introduction

Chronic non-communicable diseases (NCDs) have become the foremost public health problem threatening global human health. According to World Health Organization statistics, NCDs cause approximately 41 million deaths globally each year, accounting for 74% of all deaths, with cardiovascular diseases, cancer, chronic respiratory diseases, and diabetes being the leading causes of mortality (World Health Organization, 2025). In China, the epidemiological situation of NCDs is particularly severe. The Report on Cardiovascular Health and Diseases in China shows that in 2022, the number of people with cardiovascular diseases in China reached 330 million, the prevalence of hypertension among adults reached 27.5%, the number of diabetes patients was approximately 140 million, and the number of chronic obstructive pulmonary disease (COPD) patients was nearly 100 million (Liu et al., 2025). The disease burden caused by NCDs continues to increase, placing heavy pressure on the healthcare system.

Exercise intervention is a core strategy for the prevention and management of chronic non-communicable diseases. A large body of evidence-based medical research has shown that regular exercise can independently reduce cardiovascular disease risk by 20%-30%, reduce type 2 diabetes risk by 40%-50%, and help control body weight, blood pressure, blood lipids, and blood glucose levels (Pedersen & Saltin, 2015). However, the effectiveness of exercise intervention highly depends on the accuracy of exercise “dosage”—intensity that is too low fails to produce training effects, while intensity that is too high increases cardiovascular event risk (Ross et al., 2016). Traditional exercise prescriptions often employ empirical methods, such as the age-predicted maximum heart rate formula: Maximum heart rate = 220 - age. These methods lack assessment of individuals’ true cardiopulmonary function, resulting in inconsistent exercise intervention effects and even potential safety hazards.

Cardiopulmonary exercise testing (CPET) is a clinical trial that enables researchers to simultaneously observe patients’ cardiovascular and respiratory system responses to the same exercise stress. As a non-invasive, dynamic assessment of cardiopulmonary function, CPET can synchronously monitor gas exchange, ventilatory parameters, and electrocardiographic changes under exercise load, objectively and quantitatively measuring core indicators such as peak oxygen uptake (VO_{2peak}), anaerobic threshold (AT), and ventilatory efficiency (VE/VCO₂ slope). It is currently the “gold standard” for assessing cardiopulmonary functional reserve (Wasserman et al., 2005). In recent years, precision exercise prescription design based on CPET guidance has become an important development direction in the field of exercise rehabilitation. This review aims to systematically elaborate on the application value of CPET core indicators in exercise prescription design for chronic non-communicable disease populations, establish an exercise prescription formulation process based on CPET, and provide evidence-based support for precision exercise intervention in chronic non-communicable disease populations.

2. Basic Principles and Core Indicators of CPET

2.1 Physiological Basis of CPET

The core physiological principle of CPET is based on the Fick equation:

$$VO_2 = CO \times (CaO_2 - CvO_2)$$

That is: Oxygen uptake = Cardiac output × Arteriovenous oxygen difference

During exercise, the body’s demand for oxygen increases linearly with increasing power. CPET comprehensively assesses the integrated functional reserve and metabolic

response of the cardiopulmonary system under exercise conditions by continuously monitoring oxygen uptake (VO_2), carbon dioxide output (VCO_2), minute ventilation (VE), heart rate (HR), blood pressure (BP), and electrocardiogram (ECG) during exercise, combined with power change relationships (Wasserman et al., 2005). In clinical practice, systematic identification of exercise limiting factors can be achieved through comprehensive interpretation of the Wasserman Nine-Panel Plot, including cardiac limitation, pulmonary limitation, pulmonary vascular disease, and peripheral/muscular functional limitation (Wasserman et al., 2005).

Table 1: Exercise Limitation Factors

Limitation Type	Limiting Factors
Cardiac limitation	Early plateau of O_2 pulse, elevated VE/VCO_2
Pulmonary limitation	Exhausted ventilatory reserve, relatively preserved AT
Pulmonary vascular limitation	Significantly elevated VE/VCO_2 with decreased PETCO_2
Muscular/peripheral deconditioning	Early AT, early lactic acidosis, normal cardiopulmonary response

2.2 Selection of Incremental Load Protocol

The incremental load protocol for CPET should be

Table 3: CPET Core Indicator System and Clinical Significance

Indicator Category	Specific Indicator	Normal Reference Value	Clinical Significance
Exercise capacity	Peak oxygen uptake	$\geq 85\%$ predicted	Gold standard for cardiopulmonary functional reserve, core parameter for prognosis assessment
	Peak power	Age and gender dependent	Objective reflection of exercise tolerance
	O_2 pulse	$\geq 80\%$ predicted	Indicator of cardiac pumping function
Metabolic	Anaerobic threshold	$\geq 40\%$ $\text{VO}_{2\text{peak}}$	Core basis for exercise prescription intensity determination
	Respiratory compensation point	$> 70\%$ $\text{VO}_{2\text{peak}}$	Upper limit for high-intensity exercise
Ventilatory efficiency	VE/VCO_2 slope	Slope < 30	Most important single indicator for heart failure prognosis
	PETCO_2 at AT	≥ 36 mmHg	Screening for pulmonary vascular disease

Among the above indicator system, peak oxygen uptake is the most important indicator for assessing comprehensive cardiopulmonary functional reserve, and its percentage of predicted value is a key parameter for prognostic stratification; Anaerobic threshold represents the critical point of transition from aerobic to anaerobic metabolism and is the core physiological basis for determining exercise prescription intensity; VE/VCO_2 slope is the most important single indicator for assessing heart failure prognosis, with a normal value < 30 , and when > 45 , it indicates severely poor prognosis (Corrà et al., 2014).

3. Application Value of CPET in NCDs Exercise Prescription Design

3.1 FITT-VP Principles and CPET Guidance

The basic framework of exercise prescription follows the FITT-VP principles: Frequency, Intensity, Time, Type, Volume, and Progression (American College of Sports Medicine, 2013). In chronic non-communicable disease populations, CPET results provide objective, individualized bases for exercise prescription intensity setting and progression timing, achieving the transformation from “empirical prescription” to “precision prescription.”

3.2 CPET-Based Exercise Intensity Target Zone Setting Methods

CPET-guided exercise intensity target setting is the core of

individualized based on the subject’s estimated exercise capacity. In clinical application, the continuous linearly increasing power Ramp protocol is most commonly used. A reasonable rate of progression should control the test duration to 8-12 minutes to accurately capture the inflection points of physiological indicators. In clinical practice, different cycling power progression rates are typically selected based on individual capacity for different populations (Wasserman et al., 2005).

Table 2: Common Power Progression Rates for Cycle Ergometry

Population Type	Power Progression Rate
Healthy population	20-30 W/min
Heart failure patients	5-10 W/min
Athletes	30-50 W/min

2.3 CPET Core Indicator System

CPET core indicators can be divided into three categories: exercise capacity indicators, ventilatory efficiency indicators, and metabolic indicators. The clinical significance of each indicator is shown in Table 3.

exercise prescription precision, mainly including the following three methods:

1) **Anaerobic Threshold (AT) Method:** Using the heart rate or power corresponding to AT as the starting intensity for exercise prescription, with AT increased by 10-20% as the target intensity. The AT method is currently the most recommended CPET-driven exercise prescription design method, particularly suitable for high-risk populations such as heart failure and coronary artery disease patients. Its advantages are significant: AT is a physiological anaerobic metabolism threshold, and exercise intensity designed based on this has high safety and high correlation with the lactate threshold, with predictable training effects (Mezzani et al., 2013).

2) **$\text{VO}_{2\text{peak}}$ Percentage Method:** Determining intensity intervals based on percentages of $\text{VO}_{2\text{peak}}$. Moderate intensity corresponds to 46-63% $\text{VO}_{2\text{peak}}$ (RPE 12-13), and high intensity corresponds to 64-90% $\text{VO}_{2\text{peak}}$ (RPE 14-17). Although this method is simple and practical in operation, it does not consider individual differences in AT and may pose safety risks for high-risk populations.

3) **Heart Rate Reserve (HRR) Method:** Calculating target exercise heart rate based on the Karvonen formula: Target heart rate = Heart rate reserve \times Intensity% + Resting heart rate, where Heart rate reserve (HRR) = Maximum heart rate - Resting heart rate. Maximum heart rate is recommended to use the formula “ $208 - 0.7 \times \text{age}$ ” (Tanaka et al., 2001). The

advantage of this method is that it does not require gas analysis equipment, but it may be affected by medications such as β -blockers.

3.3 Exercise Intensity Zones and Training Mode Selection

Based on the positions of the anaerobic threshold (AT) and the second ventilatory threshold/respiratory compensation point (VT2/RCP) in CPET, combined with the patient's Rating of Perceived Exertion (RPE), exercise intensity can be divided into three zones to select the most suitable training mode for the patient.

Zone 1 (Recovery Zone): $<AT$ ($<50\% VO_{2peak}$), RPE 9-11. Suitable for initial exercise adaptation, high-risk patients, and recovery training.

Zone 2 (Aerobic Zone): $AT-VT_2$ ($50-70\% VO_{2peak}$), RPE 12-14. This intensity zone is suitable for main training for most chronic disease patients, can significantly improve cardiopulmonary function, while maintaining high safety.

Zone 3 (High-Intensity Zone): $>VT_2$ ($>70\% VO_{2peak}$), RPE 15-17. Suitable for low-risk patients with certain exercise foundations, can bring greater cardiopulmonary function improvements, but requires physician assessment before implementation.

4. Application of CPET in Exercise Prescription for Major Chronic Non-communicable Disease Populations

4.1 Cardiovascular Diseases

4.1.1 Heart Failure

Heart failure is the field where CPET application is most mature. The Weber heart function classification system (based on VO_{2peak} and AT) can quantify the severity of heart failure (Table 4), providing a basis for risk stratification in exercise rehabilitation (Wasserman et al., 2005).

Table 4: Weber Heart Function Classification

Grade	VO_{2peak} (ml/kg/min)	AT (ml/kg/min)	Cardiac Function Status
Grade A	>20	>14	Mildly impaired
Grade B	16-20	11-14	Moderately impaired
Grade C	10-16	8-11	Severely impaired
Grade D	<10	<8	Extremely severely impaired

When formulating exercise prescriptions for heart failure patients, the starting intensity should be set at 10-15 bpm below the anaerobic threshold heart rate or at 40-50% of peak oxygen uptake. The target intensity should progress to the level corresponding to the anaerobic threshold (Zone 2), with a progression rate of increasing intensity by 5% or exercise time by 5 minutes every 1-2 weeks. For patients with VE/VCO_2 slope >35 , attention should be paid to strengthening ECG and blood pressure monitoring during exercise (Corrà et al., 2014).

4.1.2 Coronary Artery Disease

CPET in coronary artery disease patients is mainly used to

identify exercise-induced myocardial ischemia thresholds, providing a safety boundary for exercise prescription intensity setting (Wasserman et al., 2005). Ischemia thresholds are typically manifested as: (1) ST-segment horizontal or downsloping depression ≥ 1 mm; (2) plateau or decrease in O_2 pulse (suggesting decreased stroke volume during exercise); (3) failure of systolic blood pressure to increase or decrease during exercise. The corresponding heart rate, power, and VO_2 represent the upper limit of exercise prescription intensity (exercise is recommended at 10 bpm below the ischemia threshold).

When formulating exercise prescriptions for coronary artery disease patients, attention should be paid to ensuring exercise intensity does not exceed the ischemia threshold heart rate minus 10 bpm, while comprehensively determining the safe target zone using the anaerobic threshold method (taking the lower of the two values). Stable coronary artery disease patients performing regular aerobic exercise below the ischemia threshold 3-5 times per week, 30-40 minutes each time, can improve vascular endothelial function, promote collateral circulation formation, and increase exercise tolerance (Anderson et al., 2016).

4.2 Type 2 Diabetes Mellitus

Type 2 diabetes mellitus patients often have decreased cardiopulmonary function and exercise intolerance. Their CPET characteristics include: peak oxygen uptake (VO_{2peak}) decreased by approximately 15-20%, anaerobic threshold (AT) occurring early ($<40\% VO_{2peak}$), chronotropic incompetence, and peripheral muscle metabolic abnormalities (Kinoshita et al., 2024).

When formulating exercise prescriptions for type 2 diabetes mellitus patients, a combination of aerobic and resistance exercise is recommended. Aerobic exercise frequency should be ≥ 3 times/week, at moderate to vigorous intensity ($50-80\% VO_{2max}$ or VO_{2R}), with duration ≥ 150 minutes/week. Exercise timing is recommended to be 1-2 hours postprandial to reduce postprandial blood glucose peaks (American Diabetes Association, 2024). Additionally, attention should be paid to monitoring blood glucose before exercise: when blood glucose is <5.6 mmol/L, supplement carbohydrates; when blood glucose is >16.7 mmol/L or urine ketones are positive, postpone exercise. Patients using insulin or sulfonylureas need to be vigilant about exercise-related hypoglycemia and are advised to carry rapid-acting glucose foods during exercise (American Diabetes Association, 2024).

4.3 Chronic Obstructive Pulmonary Disease

COPD patients show relatively obvious cardiopulmonary exercise testing results, typically characterized by exhausted ventilatory reserve ($VE_{max}/MVV >85\%$), exercise-induced hypoxemia (SpO_2 decrease $\geq 4\%$ or $<88\%$), and dynamic hyperinflation (Wasserman et al., 2005). VE/VCO_2 slope may be mildly to moderately elevated (30-40), but O_2 pulse indicators are relatively normal.

When formulating exercise prescriptions for COPD patients, it is recommended to use 60-80% of peak power (WR_{peak}) or

power corresponding to AT as the intensity target zone, prioritizing cycling or walking exercises, with lower limb aerobic training as the core content and upper limb training as supplementary (Singh et al., 2019).

4.4 Cancer Rehabilitation

Cancer patients commonly experience cancer-related fatigue (CRF). CPET can objectively assess the degree of functional impairment and provide a basis for individualized exercise prescription formulation (Schmitz et al., 2010). Cancer patients' CPET characteristics vary by cancer type and treatment regimen, but VO_{2peak} is generally decreased by 20-30%, and some patients may show elevated VE/VCO_2 slope.

When formulating exercise prescriptions for cancer rehabilitation patients, moderate-intensity aerobic exercise (40-60% VO_{2R} or HRR) is recommended, with frequency 3-5 times/week and duration ≥ 150 minutes/week; combined with low to moderate intensity resistance training (1-3 sets, 10-15 repetitions/set) 2-3 times/week to maintain muscle mass (Schmitz et al., 2010; Campbell et al., 2019).

Additionally, due to the special nature of this disease population, exercise prescription design for cancer rehabilitation patients requires special safety considerations: avoid public fitness venues when neutrophils are $<0.5 \times 10^9/L$; avoid contact sports when platelets are $<50 \times 10^9/L$; suspend exercise when hemoglobin is <8 g/dL; and avoid high-impact exercise in patients with bone metastases to prevent pathological fractures (Campbell et al., 2019).

5. CPET-Based Exercise Prescription Formulation Process

Based on the aforementioned evidence, we propose a standardized four-step process for exercise prescription formulation for NCDs populations based on CPET.

Step 1: CPET Assessment

First, use the Ramp incremental load protocol with a target test duration of 8-12 minutes. Synchronously monitor VO_2 , VCO_2 , VE, HR, BP, ECG, and SpO_2 during the test, recording VO_{2peak} , AT, VE/VCO_2 slope, O_2 pulse, blood pressure response, and ECG changes.

Step 2: Risk Stratification

Perform risk stratification based on VO_{2peak} , AT, VE/VCO_2 slope, blood pressure response, and ECG. Low-risk populations have $VO_{2peak} \geq 85\%$ predicted with no exercise blood pressure response and no myocardial ischemia; moderate-risk populations have VO_{2peak} reaching 60-84% predicted, possibly with mild exercise blood pressure response or 1-2 risk factors; high-risk populations have $VO_{2peak} < 60\%$ predicted, with obvious exercise blood pressure response or target organ damage.

Step 3: Prescription Formulation

Based on FITT-VP principles, use the anaerobic threshold as

the core indicator to determine exercise intensity. Low-risk populations exercise at intensity Zone 2 (AT-VT2); moderate-risk populations select Zone 1-2 ($<AT$ to AT); high-risk populations strictly control exercise intensity within Zone 1 ($<AT$).

Step 4: Implementation and Follow-up

During exercise prescription implementation, the first exercise session should be conducted under supervision, mainly verifying tolerability. Subsequently, assess every 2-4 weeks, adjusting exercise prescription load volume and intensity based on symptoms, perceived exertion, and blood pressure response. Recommend CPET re-evaluation every 3-6 months, with prescription progression based on functional improvement.

6. Research Progress of CPET in NCDs Exercise Rehabilitation

6.1 International Research Progress

The AHA/ACC 2022 cardiac rehabilitation guidelines explicitly recommend that all cardiovascular disease patients undergo CPET assessment before initiating exercise rehabilitation to determine exercise prescription intensity and identify potential risks (Smith et al., 2011). Systematic reviews and meta-analyses show that CPET-guided exercise rehabilitation can increase heart failure patients' VO_{2peak} by an average of 3.5 ml/kg/min and reduce all-cause mortality risk by approximately 20% (Tucker et al., 2019).

The ACSM Guidelines for Exercise Testing and Prescription (10th Edition) indicate that pre-exercise CPET assessment for diabetes patients can improve prescription safety and effectiveness (American College of Sports Medicine, 2013). Research shows that individualized exercise programs based on CPET have better effects on glycated hemoglobin (HbA1c) improvement than standardized programs, with the former reducing HbA1c by 0.7-1.0% compared to 0.5-0.7% for standardized programs (Boulé et al., 2001).

6.2 Domestic Research Progress

In recent years, Chinese scholars have conducted extensive research in the field of cardiopulmonary exercise testing and exercise rehabilitation for chronic non-communicable diseases. Professor Sun Xingguo's team systematically elaborated on the clinical application principles and methods of CPET, promoting the popularization of CPET in China. Multiple clinical studies have shown that CPET-based exercise rehabilitation can effectively improve exercise tolerance and quality of life in Chinese cardiovascular disease patients (Guazzi et al., 2018).

However, compared with developed countries, there are still gaps in the application of CPET in NCDs management in China. First, the penetration rate of CPET is seriously insufficient, with CPET equipment mainly concentrated in tertiary hospitals; second, the shortage of professional interpretation personnel limits the standardized application of results to some extent; additionally, CPET-based exercise prescriptions have not yet been included in medical insurance

payment scope, which greatly affects patient accessibility (Guazzi et al., 2018; Jones et al., 2021).

7. Limitations and Future Prospects

7.1 Current Limitations

Although the value of CPET in NCDs exercise prescription has been widely recognized, its clinical promotion still faces challenges. First, there is the issue of equipment cost—CPET equipment costs are generally high, making it difficult for primary medical institutions to popularize them; second, the shortage of professionals capable of interpreting test data limits the standardized application of results; additionally, in clinical application, some NCDs patients (such as elderly, extremely frail patients) have difficulty completing standardized CPET tests, and data interpretation is challenging in some patients due to dynamic hyperinflation or anxiety. These factors constrain the promotion and development of CPET to some extent (Guazzi et al., 2018).

7.2 Future Development Directions

With technological development, the following directions in CPET are worth anticipating. First, the rapid development of wearable devices—integrating wearable devices with CPET principles, using portable head-mounted gas analyzers and heart rate and blood pressure measurement devices to achieve real-time cardiopulmonary function monitoring during home exercise (Jones et al., 2021). Currently, portable head-mounted gas analysis devices such as VO₂Master, Calibre, and Neumafit have appeared on the market, and there are no technical bottlenecks for home exercise cardiopulmonary function monitoring. Second, with the explosive development of AI agents, machine learning algorithms can be utilized to assist in automatic interpretation of CPET reports, greatly reducing dependence on professional personnel for data interpretation. Building intelligent, individualized exercise prescription generation systems based on big data can benefit broader chronic disease and sub-healthy populations.

8. Conclusion

As the “gold standard” for assessing cardiopulmonary function, CPET provides objective, precise, and individualized scientific basis for exercise prescription design in chronic non-communicable disease populations. Through interpretation of core indicators such as VO_{2peak}, AT, and VE/VCO₂ slope, clinicians can set safe and effective exercise intensity target zones for patients, achieving precision in exercise prescriptions. Current evidence consistently shows that CPET-guided exercise prescriptions have significant advantages in improving functional status, enhancing quality of life, and improving prognosis in chronic disease populations. It is recommended that CPET be incorporated into standard assessment protocols for NCDs exercise rehabilitation at the policy level, promoting the transformation of exercise prescriptions from “empirical” to “precision-based” approaches. In the future, with the popularization of CPET technology and the cultivation of talent in exercise translational biomedicine, CPET-based exercise prescription design will become an important pillar

in the comprehensive prevention and treatment of NCDs.

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