CLINICAL REFERENCE | PROTOCOL STANDARD | QUALITY CONTROL

CPET Best Practices:
Customized Linear Ramp Protocol & Quality Control

Standardized procedures for cardiopulmonary exercise testing on an electronically-braked cycle ergometer — ensuring data quality sufficient for accurate physiological interpretation, risk stratification, and clinical decision-making.

1. PURPOSE AND SCOPE

To provide standardized procedures for performing CPET on an electronically braked cycle ergometer. Adherence to these guidelines ensures that data uploaded to CPET-Insight is of sufficient quality for accurate physiological interpretation, risk stratification, and clinical decision-making.

2. PATIENT PREPARATION

Data quality begins before the patient enters the lab. Provide the following instructions in writing at the time of scheduling.

Pre-Test Instructions for Patients

Category	Instruction
Nutrition	Eat a light meal 2–3 hours before the test. Avoid heavy, high-fat meals. Do not fast — low blood glucose will impair performance.
Caffeine & Alcohol	Avoid caffeine and alcohol for at least 8 hours prior to testing.
Smoking / Vaping	No smoking or vaping for at least 4 hours before the test; ideally 24 hours.
Exercise	Avoid strenuous exercise on the day of the test. Light activity is acceptable.
Medications	Continue all routine medications on schedule unless specifically instructed otherwise by the ordering physician. Bring a list of current medications.
Clothing	Wear comfortable athletic clothing and closed-toe athletic shoes with socks.
Hydration	Maintain normal hydration. Drink water as usual; avoid excessive fluid intake immediately before the test.

Nail Polish	Remove nail polish or artificial nails from one finger if pulse oximetry will be used.
Illness	Reschedule if the patient is acutely unwell (fever, active respiratory infection).

3. PRE-TEST SAFETY SCREENING

Verify the following before proceeding. CPET should not be performed if absolute contraindications are present. Relative contraindications require physician review and documented risk-benefit assessment.

Absolute Contraindications

- Acute myocardial infarction within the past 2 days
- Unstable angina (not stabilized medically)
- Uncontrolled cardiac arrhythmia causing symptoms or hemodynamic compromise
- Active endocarditis
- Severe symptomatic aortic stenosis
- Decompensated heart failure
- Acute pulmonary embolism, pulmonary infarction, or deep vein thrombosis
- Acute myocarditis or pericarditis
- Acute aortic dissection
- Physical disability preventing safe participation

Relative Contraindications — Physician Review Required

- Known left main coronary artery stenosis
- Moderate stenotic valvular disease
- Severe arterial hypertension at rest (SBP >200 mmHg or DBP >110 mmHg)
- High-degree AV block
- Hypertrophic cardiomyopathy with significant outflow obstruction
- Recent stroke or TIA
- Uncorrected medical conditions (e.g., severe anemia, electrolyte imbalance, hyperthyroidism)

Test Termination Criteria

Stop the test immediately and notify the supervising clinician if any of the following occur:

- Drop in systolic BP >10 mmHg from baseline despite increasing workload, with signs of ischemia
- Moderate-to-severe angina
- Increasing nervous system symptoms (ataxia, dizziness, near-syncope)
- Signs of poor perfusion (cyanosis, pallor)
- Sustained ventricular tachycardia or other serious arrhythmia
- ST-segment elevation ≥1 mm in leads without diagnostic Q-waves

- Patient request to stop
- Technical failure preventing continued safe monitoring

Emergency Preparedness: A functioning AED, supplemental oxygen, and emergency call capability must be accessible in or immediately adjacent to the testing room at all times. All testing staff must hold current Basic Life Support (BLS) certification.

4. EQUIPMENT PREPARATION & CALIBRATION

High-quality interpretation starts with precision at the sensor level. Calibration errors propagate through every calculated variable — from RER to VO_2 kinetics.

Standard Pre-Test Calibrations

a. Equipment Warm-Up

Before beginning calibration, the metabolic cart must be powered on for **20–30 minutes** (per manufacturer specifications). Never calibrate on a cold system.

b. Gas Sensor Calibration

Perform a two-point calibration on a **weekly basis**:

- **Point 1 — Room Air (Zero/Baseline):** System samples ambient air. Software assumes standard concentrations of 20.93% O_2 and 0.03% CO_2.
- **Point 2 — Reference Gas (Span):** System samples a certified medical-grade gas mixture (commonly 16% O_2 / 5% CO_2, balance Nitrogen).

Accuracy threshold: Variance >0.02% = calibration failure. Do not proceed.

c. Flow / Volume Calibration

Since VO_2 and VCO_2 are flow-weighted measurements, any error in volume translates directly into an RER error.

- **3-Liter Syringe:** A precision 3 L syringe pumped through the flow sensor (pneumotach or turbine).
- **Multi-Flow Verification:** Strokes at low, medium, and high speeds — ensuring accuracy across the full range of human ventilation (≈6 L/min resting to >150 L/min at peak).

Accuracy threshold: Measured volume must be within ±3% of 3 liters.

d. Ambient Conditions

Barometric pressure, temperature, and humidity must be updated in the system **daily**, as these affect BTPS (Body Temperature and Pressure, Saturated) corrections. Optimal testing room temperature is 20–22°C.

e. RER Verification (Resting Biological Check)

After automated calibration, perform a resting system check:

- Connect the patient interface (mask or mouthpiece)

- Observe resting RER of a healthy subject (typically the technician)
- **Expected resting RER: 0.70–0.85**
  - RER <0.70 → suggests O_2 sensor under-reading or CO_2 sensor over-reading
  - RER >1.00 at rest → suggests hyperventilation or a leak in the sampling line

f. Patient Interface — Mask Fit & Leak Check

A poorly fitted mask is one of the most common sources of artifactual data. Verify before every test:

- Select the correct mask size for the patient's face — no single size fits all.
- Perform a manual occlusion test: briefly occlude the exhalation port and confirm the flow sensor registers zero flow with no leak.
- Check for hair, facial hair, or jewelry that may break the seal.
- Re-verify mask seal during the unloaded phase before commencing the ramp.

g. Biological Calibration Program

In addition to automated sensor calibration, sites should maintain a Biological Control (BioCal) program using a designated healthy staff member at regular intervals.

- **Frequency:** Monthly, or following any major hardware or software update
- **Protocol:** Sub-maximal constant work rate test (e.g., 6 minutes at 50 W) or a standard 10 W/min ramp

Benefits of Biological Calibration:

Whole-System Verification	Standard calibration checks sensors in isolation. BioCal validates the integration of flow, gas, and timing algorithms through a known biological response.
Drift Detection	Identifies subtle leaks or sensor drift that pass standard automated calibration.
Longitudinal Stability	Ensures data consistency across months and years, enabling valid serial comparisons.
Expected Coefficients of Variation	Heart rate ≤5% | VO_2 ≤6% | VCO_2 ≤6% | VE/VCO_2 ≤10% | Breathing frequency ≤8%

5. PROTOCOL DESIGN: THE 10-MINUTE LINEAR RAMP

To achieve the optimal exercise duration of 8–12 minutes, the ramp increment must be customized to the patient's predicted capacity using the following equation:

$$\text{Ramp Rate (W/min)} = [\ VO_2\text{peak (pred)} - VO_2\text{unloaded (pred)}\ ] \div 100$$

$$\text{where: } VO_2\text{unloaded (mL/min)} \approx 150 + (6 \times \text{weight in kg})$$

The divisor 100 is derived from the average oxygen cost of 10.3 mL/min/W over a 10-minute duration.

6. TESTING PROCEDURES

Phase	Duration	Description
Rest	3 min	Patient sits quietly; establishes baseline RER and VE. Confirm mask seal and confirm resting RER is within expected range (0.70–0.85).
Unloaded	3 min	Pedaling at 60–70 RPM with zero resistance; establishes active baseline. Re-verify mask seal before starting ramp.
Exercise	**8–12 min**	Customized linear ramp at constant cadence (60–70 RPM). Encourage patient verbally at regular intervals. Monitor for termination criteria throughout.
Recovery	≥5 min	Zero resistance; continue monitoring. Assess O_2 kinetics and HR recovery. Do not remove mask prematurely.

7. QUALITY CONTROL & DATA INTEGRITY

Verify the following before uploading data to CPET-Insight. Submissions that do not meet QC standards may be returned with warnings and may require resubmission. **Feedback quality will only be as good as the data uploaded.**

1. **RPM Stability**
   Constant cadence of 60–70 RPM must be maintained throughout the exercise phase. Significant cadence drift invalidates the work rate signal.

2. **Maximal Effort**
   RER >1.05 and/or peak HR >85% of age-predicted maximum (220 – age). Both criteria support true cardiorespiratory limitation.

3	**Signal Integrity** No excessive noise, signal dropout, or implausible values in the breath-by-breath data. Data averaging method (breath-by-breath or rolling average) must be consistent across tests.
4	**Protocol Adherence** Ramp rate, test duration (8–12 min), and four-phase structure all as specified. Document reason for any deviation.
5	**Equipment Calibration Confirmed** Calibration log verified for the test session date. Do not upload data from a session with a failed or incomplete calibration record.
6	**Mask Integrity at Peak** Confirm no visible mask leak occurred at peak exercise. A peak leak will cause artifactually elevated VO_2 and underestimated RER.
7	**Resting Baseline Stability** A minimum of 2 minutes of stable resting data is required. Confirm resting RER 0.70–0.85 before commencing the unloaded phase.

8. STAFFING & COMPETENCY

CPET data quality is directly dependent on the skill and training of the operator. The following minimum requirements apply to all sites submitting data to CPET-Insight.

Minimum Staffing Per Test Session

- **Lead Practitioner:** A trained healthcare professional who has completed formal CPET education covering exercise physiology, protocol selection, safety monitoring, ECG interpretation during exercise, and data quality assessment.
- **Second Person:** An additional individual present and able to assist with patient safety, emergency response, and equipment management.

Competency Maintenance

- Minimum of **25 CPET tests per year** recommended to maintain technical proficiency.
- Periodic peer review of interpretive or technical skills.
- Continuing education reflecting current CPET guidelines and literature.

9. ANNUAL ERGOMETER CALIBRATION

Metabolic data is only as accurate as the work rate being applied to the patient. An ergometer that is mis-reporting power output (watts) or cadence (RPM) will cause systematic error in every derived CPET variable — including VO_2/work rate slope, oxygen cost of unloaded work, and ramp rate calculations. All sites must ensure that the cycle ergometer undergoes annual calibration by the manufacturer or a certified service technician.

Component	Verification Method	Accepted Accuracy
Power Output (Watts)	Calibrated external power meter or manufacturer dynamometer; verified at multiple target loads (25 W, 50 W, 100 W, 150 W, 200 W)	**±2% of target load or ±3 W (whichever is greater) at loads above 25 W**
Cadence Sensor (RPM)	Optical tachometer or manufacturer test fixture; verified at 40, 60, and 80 RPM	**±1 RPM across the clinically relevant range (40–100 RPM)**
Resistance Linearity	Incremental loading test; confirm that power output increases linearly with commanded load across the full working range	**No step-discontinuities or plateau; smooth linear response required**
Electronic Brake System	Inspect electromagnetic brake coils and controller board; confirm auto-compensation for RPM variation	Brake must maintain target wattage within tolerance regardless of cadence fluctuation
General Mechanical Inspection	Pedals, crank arm, seat post, handlebar clamps, belt/chain tension, and all moving parts inspected and lubricated per manufacturer schedule	No excessive wear; all safety-critical fasteners within torque spec

Documentation Requirements

- The service technician must provide a **written calibration report** at the conclusion of every annual service visit.
- The report must document: date of service, technician name and certification, all test results (pre- and post-adjustment), and any corrective actions taken.
- Calibration records must be retained for a **minimum of 2 years** and must be available for audit upon request.
- If calibration fails acceptance criteria, the ergometer must be taken out of service until corrections are verified by re-testing.