Executive Certificate in Cardiopulmonary Exercise Testing for Cardiovascular Health (United Kingdom)

Cardiopulmonary Exercise Testing Foundations

VO2 max – The highest rate at which oxygen can be taken up, transported and utilised during exhaustive exercise. It is expressed in millilitres of oxygen per kilogram body mass per minute (ml·kg-1·min-1). VO2 max is considered the gold-standard indicator of aerobic capacity and is often used to stratify cardiovascular risk, prescribe training intensity and monitor disease progression. For example, a healthy 30-year-old male may achieve a VO2 max of 55 ml·kg-1·min-1, whereas a patient with chronic heart failure may be limited to 15 ml·kg-1·min-1.

V̇O2peak – The highest oxygen uptake measured during a graded exercise test when a true plateau cannot be demonstrated. In many clinical protocols a plateau is not observed, so V̇O2peak is reported instead of VO2 max. It is important to distinguish the two because V̇O2peak may underestimate true maximal capacity if the test is terminated early due to symptoms or equipment limits.

Anaerobic threshold (AT) – The exercise intensity at which lactate begins to accumulate in the blood, reflecting a shift from predominantly aerobic metabolism to a greater contribution of anaerobic glycolysis. AT is typically identified by a systematic increase in the ventilatory equivalent for carbon dioxide (VE/VCO2) or by the point at which the respiratory exchange ratio (RER) exceeds 0.85. Clinicians use AT to set sub-maximal training zones that are sustainable for long-duration rehabilitation programmes.

Lactate threshold (LT) – Similar to AT but defined by the blood lactate concentration rising above a predetermined baseline (often 2 mmol·L-1). Lactate threshold provides a biochemical marker of metabolic stress and may be measured via capillary or arterial sampling during incremental exercise. In practice, LT often coincides with the ventilatory threshold identified on the gas exchange curve, allowing non-invasive estimation of the same physiological point.

Ventilatory threshold (VT) – The point during incremental exercise where ventilation (VE) begins to increase disproportionately to carbon dioxide output (VCO2). VT is detected by a systematic rise in VE/VCO2 and is considered a reliable surrogate for AT/LT in settings where blood sampling is impractical. VT is useful for prescribing endurance training that stays below the point where breathlessness becomes limiting.

Respiratory exchange ratio (RER) – The ratio of carbon dioxide production to oxygen consumption (VCO2/VO2). RER values below 0.7 Indicate predominant fat oxidation, values around 0.85 Reflect mixed substrate use, and values above 1.0 Signal carbohydrate dominance and increasing reliance on anaerobic metabolism. An RER of 1.10–1.15 Is commonly used as a criterion for maximal effort in cardiopulmonary exercise testing (CPET).

Minute ventilation (VE) – The total volume of air moved in and out of the lungs per minute. VE is calculated as tidal volume (VT) multiplied by breathing frequency (f). During incremental exercise VE rises linearly with VO2 until the ventilatory threshold, after which the slope steepens. Monitoring VE helps identify abnormal ventilatory responses such as hyperventilation or ventilatory limitation.

Tidal volume (VT) – The volume of air inhaled or exhaled with each breath. VT increases with exercise intensity due to recruitment of additional respiratory muscles and changes in lung mechanics. In healthy individuals VT typically rises from ~0.5 L at rest to 2–3 L at maximal effort.

Breathing frequency (f) – The number of breaths per minute. F rises progressively during exercise, contributing to the increase in VE. A high f with a relatively low VT may indicate a restrictive ventilatory pattern, whereas a low f with a high VT suggests a more efficient breathing strategy.

Ventilatory equivalents – Ratios that relate ventilation to gas exchange: VE/VO2 (ventilatory equivalent for oxygen) and VE/VCO2 (ventilatory equivalent for carbon dioxide). These values provide insight into the efficiency of the respiratory system. A low VE/VO2 indicates efficient oxygen uptake, whereas a high VE/VCO2 may signal ventilatory inefficiency, as seen in heart failure or pulmonary hypertension.

Oxygen pulse (O2 pulse) – The amount of oxygen consumed per heartbeat, calculated as VO2/heart rate (HR). O2 pulse approximates stroke volume × arterial-venous oxygen difference. A rising O2 pulse during incremental exercise reflects increasing stroke volume and/or improved peripheral extraction. A plateau or decline may signify cardiac limitation.

Heart rate reserve (HRR) – The difference between maximal heart rate (HRmax) and resting heart rate (HRrest). HRR is used to prescribe exercise intensity as a percentage of the available heart rate range, providing a more individualized approach than fixed percentages of HRmax.

Chronotropic incompetence – The inability of the heart to increase its rate appropriately with rising metabolic demand. It is defined as a failure to achieve at least 80 % of the predicted HR reserve during maximal exercise. Chronotropic incompetence is associated with poorer prognosis in heart failure and may influence the interpretation of CPET results.

Ventilatory limitation – A condition in which the maximal ventilatory capacity (MVV) is approached or exceeded before the cardiovascular system limits exercise. It is identified when VE reaches ≥85 % of MVV at sub-maximal VO2. Common causes include severe obstructive lung disease, restrictive chest wall disorders, or neuromuscular weakness.

Mechanical efficiency – The ratio of external work performed to the metabolic energy expended, often expressed as the slope of VO2 versus work rate. In cycling, a typical mechanical efficiency is 20–25 %. Reduced efficiency may indicate peripheral muscle dysfunction or impaired mitochondrial oxidative capacity.

Peripheral oxygen extraction – The ability of skeletal muscle to remove oxygen from arterial blood, reflected by the arteriovenous oxygen difference (a-vO2 diff). Peripheral extraction can be estimated indirectly from the O2 pulse and cardiac output data. Reduced extraction is common in patients with peripheral artery disease or chronic obstructive pulmonary disease (COPD).

Cardiac output (CO) – The volume of blood the heart pumps per minute, calculated as stroke volume × HR. In CPET, CO can be measured invasively (thermodilution or Fick principle) or estimated non-invasively using gas exchange data and assumed a-vO2 diff values. Accurate CO measurement is essential for differentiating

cardiac from pulmonary limitations.

Stroke volume (SV) – The amount of blood ejected by the left ventricle with each contraction. SV rises rapidly in the early phases of exercise, plateauing at moderate intensities, and may decline at very high workloads if afterload becomes excessive. SV can be inferred from O2 pulse trends when HR is known.

Systemic vascular resistance (SVR) – The resistance that must be overcome to push blood through the systemic circulation. SVR typically falls during exercise due to vasodilation of active muscles. An abnormal failure of SVR to decrease may indicate endothelial dysfunction or heightened sympathetic tone.

Pulmonary capillary blood volume (Vc) – The volume of blood within the pulmonary capillary network available for gas exchange. Vc can be estimated from the relationship between alveolar ventilation and diffusing capacity during CPET. Reduced Vc is observed in interstitial lung disease and contributes to diffusion limitation.

Diffusing capacity for carbon monoxide (DLCO) – A measure of the lung's ability to transfer gas from alveoli to blood, often assessed at rest but also valuable in CPET when paired with exercise-induced changes. A low DLCO suggests alveolar-capillary membrane pathology, which may limit VO2 despite normal ventilation.

Ventilatory reserve – The difference between maximal voluntary ventilation (MVV) and the highest VE achieved during the test. A ventilatory reserve 250 mmHg or diastolic > 115 mmHg, (5) severe arrhythmia, (6) patient request.

Predicted values – Normative data derived from healthy populations used to interpret individual test results. Predicted VO2 max, HRmax, and ventilatory thresholds are adjusted for age, sex, height and weight. Using appropriate reference equations (e.G., Wasserman, Jones) is essential for accurate risk stratification.

Reference equations – Mathematical models that estimate expected physiological values based on demographic variables. For CPET, common equations include the Wasserman equation for VO2 max, the Tanaka equation for HRmax (HRmax = 208 – 0.7 × Age), and the Wasserman prediction for VE/VCO2 slope.

Ventilatory efficiency slope (VE/VCO2 slope) – The linear relationship between minute ventilation and carbon dioxide output from the start of exercise to the ventilatory threshold. A high VE/VCO2 slope (> 34 in heart failure) indicates inefficient ventilation and is an independent prognostic marker in cardiac disease.

Oxygen uptake kinetics – The rate at which VO2 rises to meet the metabolic demand at the onset of exercise (phase I–III). The time constant (τ) of the primary component (phase II) reflects the speed of cardiovascular and muscular adaptation. Slower kinetics are observed in heart failure and can be quantified using a mono-exponential fit.

Recovery VO2 – The rate at which oxygen consumption declines after cessation of exercise. A rapid VO2 recovery (τ 35 adds incremental risk.

Cardiopulmonary rehabilitation – Structured programmes that combine exercise training, education and psychosocial support. CPET provides the baseline metrics (e.G., AT, VO2 max) needed to individualise prescription, monitor progress and adjust intensity over time.

Exercise prescription – The translation of CPET findings into specific training recommendations, typically expressed as a percentage of HR reserve, VO2 reserve, or work rate relative to AT. For instance, a patient may be instructed to exercise at 60 % of VO2 reserve, which corresponds to a treadmill speed of 4 km·h-1 with a 2 % incline.

Training zones – Distinct intensity ranges derived from CPET data: (1) Low-intensity zone (below 40 % VO2 reserve), (2) moderate-intensity zone (40-70 % VO2 reserve or between AT and VO2 max), (3) high-intensity zone (above VO2 max or near maximal effort). Clear delineation of zones enhances safety and effectiveness of rehabilitation.

Progress monitoring – The periodic re-assessment of CPET variables to gauge adaptation to training. Increases in VO2 max, shifts in AT to higher work rates, and improvements in ventilatory efficiency are common markers of successful intervention.

Equipment calibration – The routine verification of gas analyser accuracy, flow meter precision and treadmill or cycle ergometer resistance. Calibration must be performed before each testing session using certified gas mixtures and flow standards to ensure data validity.

Gas analyser – The device that measures inspired and expired O2 and CO2 concentrations, typically using paramagnetic or infrared sensors. Accurate gas analysis is essential for calculating VO2, VCO2 and RER. Regular maintenance includes sensor cleaning and zero-point checks.

Flow meter – The component that records the volume of air moving through the breathing circuit. Types include turbine, pneumotachometer and ultrasonic flow meters. Flow linearity and response time affect the fidelity of breath-by-breath data.

Breathing circuit – The assembly of tubing, filters, and mouthpiece or facemask that connects the participant to the gas analyser. Low-dead-space circuits minimise dilution of expired gases and improve measurement accuracy.

Mouthpiece vs facemask – Two configurations for delivering the breathing circuit. A mouthpiece is preferred for maximal effort tests because it reduces resistance and allows for a natural breathing pattern, whereas a facemask may be used for patients who cannot tolerate a mouthpiece.

Calibration gases – Certified mixtures of known O2 and CO2 concentrations (e.G., 16 % O2, 5 % CO2) used to set analyzer baselines. The frequency of calibration (daily or before each test) depends on the analyser's stability and manufacturer recommendations.

Signal acquisition – The process of recording physiological data (ECG, blood pressure, gas exchange) at a high sampling rate (typically ≥ 10 Hz) to capture rapid changes. High-resolution data enable accurate detection of ventilatory thresholds and arrhythmias.

Data smoothing – The application of moving-average or low-pass filters to raw breath-by-breath data to reduce noise while preserving physiologically relevant trends. Over-smoothing can obscure important inflection points, so a balance must be struck.

Quality control – The set of procedures to verify that CPET data meet predefined standards, including acceptable breath-by-breath variability, stable baseline, and appropriate test duration. Quality control flags are documented and, if necessary, the test is repeated.

Test reproducibility – The degree to which repeated CPETs yield consistent results under similar conditions. Intra-individual coefficients of variation for VO2 max are typically 34 and chronotropic incompetence are strong prognostic markers for transplant listing.

Heart failure with preserved ejection fraction (HFpEF) – A syndrome of diastolic dysfunction where CPET may reveal normal VO2 max but an exaggerated VE/VCO2 slope and early ventilatory limitation due to impaired ventricular filling.

Coronary artery disease (CAD) – Atherosclerotic narrowing of coronary vessels. Exercise-induced ST-segment changes combined with a VO2 plateau can confirm flow-limited disease, guiding revascularisation decisions.

Aortic stenosis – A valvular disease that restricts left-ventricular outflow. CPET can unmask severe stenosis by demonstrating an inability to increase stroke volume, resulting in a flattened O2 pulse curve and early ventilatory limitation.

Valvular regurgitation – Insufficiency of cardiac valves leading to volume overload. CPET may show a hyperdynamic response with high VO2 but reduced efficiency (elevated VE/VCO2) due to compensatory mechanisms.

Pericardial disease – Conditions such as constrictive pericarditis that limit ventricular filling. CPET typically reveals a blunted VO2 response, early rise in HR, and a low O2 pulse.

Obesity – Excess body mass that influences CPET interpretation. Absolute VO2 values may be preserved, but when normalised to total body weight they appear reduced. Using fat-free mass or allometric scaling improves accuracy.

Age-related decline – A physiological reduction in VO2 max of approximately 1 % per year after the third decade of life. Age-adjusted predicted equations account for this decline, allowing appropriate comparison across age groups.

Sex differences – Women generally achieve lower absolute VO2 max values than men due to smaller heart size, lower haemoglobin concentration and different muscle fibre composition. Sex-specific reference values are essential for fair assessment.

Altitude effects – Reduced barometric pressure leads to lower arterial oxygen tension, decreasing VO2 max by roughly 1 % per 100 m above sea level. CPET at altitude requires adjustment of predicted values and may be used to assess acclimatisation.

Environmental temperature – High ambient temperatures increase skin blood flow and reduce central blood volume, potentially limiting VO2 max. Conversely, cold exposure may increase peripheral vasoconstriction and raise VO2 for a given workload.

Medication influences – Beta-blockers blunt HR response and may lower VO2 max; calcium-channel blockers can affect vascular tone; nitrates may improve exercise tolerance by reducing afterload. Understanding these effects is crucial when interpreting CPET data.

Safety screening – A pre-test questionnaire that evaluates contraindications such as unstable angina, uncontrolled arrhythmias, recent myocardial infarction, severe hypertension, or active infection. The screening ensures that only suitable candidates undergo CPET.

Emergency protocols – Established procedures for managing adverse events during CPET, including sudden cardiac arrest, severe bronchospasm or syncope. Immediate availability of defibrillators, oxygen, bronchodilators and trained personnel is mandatory.

Informed consent – A documented process whereby participants receive clear information about the purpose, risks, benefits and alternatives to CPET, and voluntarily agree to proceed. Consent forms must be signed and retained according to institutional policies.

Data reporting – The structured presentation of CPET results, typically including demographics, protocol details, maximal values (VO2 max, HRmax, VE max), ventilatory efficiency parameters, threshold locations and any abnormal findings. Reports should be concise yet comprehensive for referring clinicians.

Interpretation algorithm – A stepwise approach to determine the primary limitation of exercise: (1) Assess ventilatory reserve, (2) evaluate O2 pulse trend, (3) examine VE/VCO2 slope, (4) review HR response, (5) consider gas exchange abnormalities, and (6) integrate clinical history.

Clinical decision-making – Using CPET outcomes to guide management, such as referral for cardiac transplantation when VO2 max 45, or adjusting medication dosages based on chronotropic response.

Research applications – CPET serves as an objective endpoint in clinical trials evaluating novel therapies, exercise interventions or device implantation. Standardised protocols and rigorous data handling enhance reproducibility and translational relevance.

Educational resources – Textbooks, peer-reviewed journals, professional societies (e.G., British Association for Cardiovascular Prevention and Rehabilitation) and accredited CPET workshops provide ongoing learning opportunities for practitioners.

Continuing professional development – Maintaining competence in CPET requires periodic training, attendance at conferences, and engagement with case-based learning. Accreditation bodies often require documented hours of CPET-related education for recertification.

Ethical considerations – Respect for patient autonomy, confidentiality of test results and equitable access to CPET services are fundamental ethical principles. When allocating limited CPET slots, prioritisation should be based on clinical need and potential impact on outcomes.

Interdisciplinary collaboration – Effective CPET delivery involves cardiologists, pulmonologists, physiotherapists, exercise physiologists, nurses and biomedical engineers. Clear communication channels and shared protocols improve test quality and patient safety.

Standard operating procedures – Written documents that outline each step of the CPET process, from equipment setup to data archiving. SOPs ensure consistency across operators and facilitate audit and quality improvement initiatives.

Audit and feedback – Regular review of CPET performance metrics (e.G., Test completion rates, adverse event frequency, adherence to termination criteria) provides insight into service quality and identifies areas for improvement.

Documentation – Accurate recording of test parameters, patient responses, ECG tracings, blood pressure readings and any interventions during CPET is essential for medico-legal protection and longitudinal patient care.

Archiving – Secure storage of raw CPET data files, calibrated reports and consent forms for at least the period mandated by local regulations (often 7–10 years). Digital archiving systems should incorporate encryption and backup protocols.

Future directions – Emerging technologies such as wearable metabolic sensors, non-invasive cardiac output monitors and machine-learning algorithms for automated threshold detection promise to enhance CPET accessibility and precision. Integration with electronic health records may enable real-time risk stratification and personalised treatment pathways.

Barriers to implementation – Common challenges include limited availability of calibrated equipment, insufficient trained staff, lack of reimbursement pathways and variability in referral patterns. Addressing these obstacles requires institutional commitment, advocacy and demonstration of CPET's cost-effectiveness.

Cost-effectiveness – Economic analyses have shown that CPET-guided pre-operative assessment can reduce postoperative complications and length of hospital stay, ultimately saving healthcare resources. Demonstrating such value supports funding for CPET services.

Quality improvement initiatives – Targeted projects such as reducing test termination due to artefact, improving patient comfort with mouthpiece design, or streamlining data entry can lead to measurable gains in test reliability and patient satisfaction.

Patient education – Providing clear instructions on pre-test preparation (e.G., Abstaining from caffeine, avoiding heavy meals) and explaining the purpose of each test phase enhances cooperation and reduces anxiety.

Psychological factors – Anxiety, depression and fear of exertion can affect performance and mask true physiological capacity. Incorporating brief psychometric assessments and offering reassurance can mitigate these effects.

Cultural competence – Sensitivity to language barriers, health beliefs and socioeconomic factors ensures that CPET is delivered equitably across diverse populations. Translating consent forms and providing interpreter services are practical steps.

Tele-CPET – Remote delivery of exercise testing using portable metabolic carts and video supervision is an emerging model, particularly relevant in post-pandemic healthcare. Validation studies are required to confirm equivalence with laboratory-based testing.

Standardisation across centres – Harmonising protocol parameters, calibration procedures and reporting formats enables multi-centre research collaborations and benchmarking of performance metrics.

Regulatory compliance – Laboratories performing CPET must adhere to national health and safety regulations, medical device directives and data protection laws. Regular inspections and certification audits verify compliance.

Professional networking – Participation in specialist interest groups, online forums and collaborative research networks fosters knowledge exchange and promotes best practice dissemination.

Mentorship – Pairing novice CPET operators with experienced mentors accelerates skill acquisition, reinforces safety culture and enhances interpretative confidence.

Simulation training – Use of high-fidelity mannequins or virtual reality platforms for practising emergency response during CPET improves preparedness for rare adverse events.

Continuing research – Ongoing investigations into the prognostic significance of novel CPET indices, such as the O2 uptake kinetics time constant or the VE/VCO2 slope during recovery, will refine risk stratification models.

Data integration – Linking CPET results with imaging modalities (e.G., Cardiac MRI, echocardiography) and biomarker profiles (e.G., NT-proBNP) creates comprehensive phenotypes that guide precision medicine approaches.

Personalised rehabilitation – Tailoring exercise programmes based on individual CPET thresholds, ventilatory efficiency and symptom profiles maximises adherence and therapeutic benefit.

Implementation science – Studying the factors that influence adoption of CPET within healthcare systems helps identify effective strategies for scaling up services.

Outcome measurement – Tracking longitudinal changes in VO2 max, AT, and VE/VCO2 slope after interventions provides objective evidence of efficacy and informs clinical guidelines.

Policy development – Evidence from CPET research contributes to national recommendations on pre-operative assessment, heart failure management and pulmonary rehabilitation pathways.

International collaboration – Sharing CPET data across borders facilitates the creation of global reference databases, enhancing the relevance of predictive equations for diverse populations.

Ethical research conduct – Ensuring informed consent, data anonymity and appropriate oversight when using CPET in clinical trials upholds research integrity.

Public health impact – By identifying individuals with low functional capacity, CPET can inform

community-level interventions aimed at reducing cardiovascular morbidity and mortality.

Technology transfer – Partnerships with industry to develop user-friendly, cost-effective CPET devices expand access to this diagnostic tool in low-resource settings.

Standardised terminology – Consistent use of key terms such as “ventilatory threshold” and “oxygen uptake kinetics” avoids confusion and promotes clear communication among multidisciplinary teams.

Training certification – Accredited programmes that assess theoretical knowledge and practical competence ensure that CPET operators meet high standards of practice.

Continuing audit – Periodic review of test accuracy, operator performance and patient outcomes sustains quality over time.

Risk mitigation – Implementing checklists for equipment setup, emergency preparedness and data verification reduces the likelihood of adverse events during CPET.

Patient-centred care – Aligning CPET objectives with the individual’s health goals, preferences and lifestyle enhances motivation and treatment adherence.

Behavioural change support – Integrating motivational interviewing techniques during CPET consultation can encourage patients to adopt healthier exercise habits.

Interoperability – Ensuring that CPET software can exchange data with hospital information systems streamlines workflow and facilitates multidisciplinary review.

Data visualisation – Presenting CPET results with clear graphs of VO2 versus work rate, VE/VCO2 slope and O2 pulse trends aids clinicians in rapid interpretation.

Standardised reporting templates – Using uniform sections for demographics, protocol details, maximal values and interpretation reduces variability and improves clarity.

Documentation of limitations – Explicitly noting factors that may have compromised test validity (e.G., Equipment malfunction, patient fatigue) assists downstream clinicians in contextualising results.

Feedback loops – Providing participants with immediate, understandable summaries of their performance can reinforce positive behaviour and improve engagement in subsequent rehabilitation sessions.

Cultural adaptation – Modifying CPET protocols to accommodate traditional clothing, religious practices or mobility aids ensures inclusivity without compromising data quality.

Remote monitoring – Incorporating wearable heart rate and oxygen saturation devices during home-based exercise can complement laboratory CPET, extending the monitoring window.

Translational impact – Applying CPET findings to real-world interventions, such as adjusting medication dosages based on chronotropic response, bridges the gap between diagnostics and therapeutic action.

Stakeholder engagement – Involving patients, clinicians, administrators and payers in the design of CPET

services promotes alignment with clinical needs and financial sustainability.

Quality metrics – Defining key performance indicators such as test completion rate, adverse event incidence, and turnaround time for report delivery supports continuous improvement.

Standard operating environment – Maintaining a quiet, temperature-controlled room with adequate lighting reduces external influences on breathing pattern and patient comfort.

Calibration schedule – Establishing a routine (e.G., Daily gas analyser checks, weekly flow meter verification) ensures consistent measurement accuracy across testing days.

Instrument maintenance – Regular servicing of cycle ergometers, treadmills and gas analysis components prevents drift and prolongs equipment lifespan.

Staff competency – Routine competency assessments, including mock scenarios and competency checklists, verify that operators maintain high skill levels.

Patient positioning – Ensuring proper alignment on the cycle seat or treadmill, with appropriate strap usage, optimises biomechanical efficiency and reduces injury risk.

Protocol selection – Choosing between ramp, stepped or protocol-specific designs based on patient fitness, clinical indication and research objectives maximises relevance of the data collected.

Safety harness – Using a harness system for treadmill testing prevents falls, particularly in patients with balance impairments or high fall risk.

Emergency drills – Conducting regular simulations of cardiac arrest, severe bronchospasm and syncope during CPET reinforces rapid, coordinated response.

Documentation of adverse events – Detailed recording of any complications, interventions performed and patient outcomes is essential for quality assurance and medico-legal protection.

Post-test debrief – Discussing results with the patient, addressing concerns, and outlining next steps enhances understanding and encourages adherence to prescribed interventions.

Long-term follow-up – Scheduling repeat CPET at appropriate intervals (e.G., 6-Monthly for heart failure patients) enables tracking of disease trajectory and effectiveness of therapeutic modifications.

Interdisciplinary case conferences – Presenting CPET findings alongside imaging and laboratory data facilitates comprehensive treatment planning.

Standardised nomenclature – Adopting internationally recognised abbreviations (e.G., VO2, VCO2, VE) reduces ambiguity in communication and documentation.

Peer review – Subjecting CPET reports to peer review, especially in research settings, improves methodological rigour and interpretative accuracy.

Ethical data sharing – When contributing CPET datasets to collaborative repositories, ensuring

de-identification and adherence to consent terms protects participant privacy.

Regulatory updates – Keeping abreast of changes in medical device regulations, data protection laws and clinical guidelines ensures ongoing compliance.

Professional societies – Engaging with organisations such as the European Society of Cardiology or the American College of Sports Medicine provides access to consensus statements, position papers and educational webinars.

Continuing education – Attending workshops on advanced topics like breath-by-breath variability analysis, machine-learning threshold detection and novel biomarkers expands expertise.

Mentor-led research projects – Involving trainees in CPET research under experienced supervision builds capacity and fosters innovation.

Publication – Disseminating findings from CPET studies in peer-reviewed journals contributes to the evidence base and informs clinical practice guidelines.

Data reproducibility – Sharing raw CPET datasets alongside analytical scripts enables other researchers to replicate analyses and validate conclusions.

Patient-reported outcomes – Incorporating questionnaires on dyspnoea, fatigue and quality of life alongside CPET results provides a holistic view of functional status.

Integration with tele-rehabilitation – Linking CPET-derived exercise prescriptions with remote monitoring platforms supports supervised home-based programmes.

Health economics – Conducting cost-utility analyses of CPET-guided interventions informs resource allocation decisions at the policy level.

Standardisation of reference values – Collaborating internationally to develop age-, sex- and ethnicity-specific normative data enhances the precision of CPET interpretation across diverse populations.

Implementation of AI tools – Deploying algorithms that automatically identify ventilatory thresholds, calculate VE/VCO2 slope and flag abnormal patterns accelerates reporting and reduces inter-operator variability.

Ethical AI use – Ensuring transparency, validation and avoidance of bias when applying machine-learning models to CPET data safeguards patient interests.

Future research gaps – Areas such as the prognostic value of O2 pulse dynamics in non-cardiac disease, the impact of novel pharmacotherapies on ventilatory efficiency, and the role of CPET in frailty assessment remain ripe for exploration.