Predicted Peak VO_2 Equations in Cardiopulmonary Exercise Testing (CPET)

Choosing a reference standard for the healthy general population, comparing the major equations, and why CPET-Insight defaults to Wasserman

Every cardiopulmonary exercise test (CPET) ends with a single, decisive number: peak oxygen uptake (Peak VO_2). On its own, an absolute value in liters per minute (**L/min**) means little. It becomes clinically actionable when it is compared with a **predicted value** — what a healthy, untrained person of the same sex, age, height, and weight would be expected to achieve. That comparison, expressed as **percent-predicted (%)**, is what classifies impairment, tracks disease, and informs decisions about transplants, surgery, medical and lifestyle therapy. The choice of **which prediction equation** generates that expected value is therefore not a cosmetic preference — it sets the denominator of every percent-predicted result a lab reports.

A reference equation has one job: to describe the normal expectation for a **healthy, untrained (relatively sedentary) general population** — not athletes, and not patients already known to have a specific disease. This resource summarizes the most used adult Peak VO_2 reference equations for that purpose, compares their strengths, weaknesses, and best-fit populations, reviews the reported accuracy of each, and explains why CPET-Insight uses the Wasserman (Hansen/Wasserman) equation as its default while fully supporting customers who prefer alternatives. It synthesizes the reference-value chapter of the 6th edition of *Wasserman & Whipp's Principles of Exercise Testing and Interpretation* (2021) with the peer-reviewed literature published since.

Why the choice of equation matters

A reference equation feeds three downstream decisions. First, **interpretation**: percent-predicted Peak VO_2 drives the classification of impairment and its prognostic weight, and different equations can shift the same patient's result by several percentage points. Second, **test design**: predicted Peak VO_2 anchors the customized ramp-rate calculation, so a mis-specified prediction produces a ramp that is too shallow (the patient fatigues from duration) or too steep (the test ends before a true peak). Third, **serial comparison**: tracking a patient against their own prior tests is valid only when the **same** equation is used each time. Mixing equations across serial studies confounds real physiological change with a change in the yardstick.

Two structural issues recur across all equations. The first is **body size and obesity**. Expressing Peak VO_2 as mL/min/kg inflates the apparent deficit in heavier patients because body mass in the denominator includes metabolically inactive fat. Equations that handle weight well — by using ideal weight, adding a defined oxygen cost for excess mass, or modeling lean body mass — behave very differently in obese patients from those that ignore weight entirely. The second is **exercise mode**: Peak VO_2 on a cycle ergometer is roughly 89–95% of the treadmill value, so a cycle-derived equation should be applied to cycle tests and a treadmill-derived equation to treadmill tests.

Commonly used equations

The equations below are the core set used in modern Western practice, all derived from healthy reference populations. Units differ by source and are labeled explicitly; in all cases age is in **years**, height in **cm**, and weight in **kg** unless noted.

Hansen / Wasserman (cycle): The CPET-Insight default

Derived by Hansen, Sue, and Wasserman (1984) from **77 men (mean age 54) judged cardiorespiratory normal** — selected from 265 tested of 400 current or former Southern California shipyard workers — who performed cycle ergometry to exhaustion with full noninvasive and intra-arterial measurements. The sample deliberately retained smokers, obese, and hypertensive men whose systems were otherwise normal. From this cohort the authors concluded that, for an overweight man, **age and height predict Peak VO_2 better than age and weight** — the origin of the equation's ideal-weight design. The companion equations for women were added later (Hansen, written communication, 2001) rather than derived from a female cohort; the equations were also made compatible with the larger Bruce/Hansen treadmill data from Seattle. It uses sex, age, height, and **predicted ideal weight**, with a secondary adjustment for the difference between actual and ideal weight. The form CPET-Insight applies (mL/min):

> **MEN** ideal_wt = 0.79 × height − 60.7
> if actual ≥ ideal: PeakVO2 = ideal_wt × (50.72 − 0.372 × age) + 6 × (actual − ideal)
> if actual < ideal: PeakVO2 = actual_wt × (50.72 − 0.372 × age)
>
> **WOMEN** ideal_wt = 0.65 × height − 42.8 (use age 30 if younger than 30)
> if actual ≥ ideal: PeakVO2 = (ideal_wt + 43) × (22.78 − 0.17 × age) + 6 × (actual − ideal)
> if actual < ideal: PeakVO2 = (actual_wt + 43) × (22.78 − 0.17 × age)

The constant 6 mL/min/kg is the oxygen cost of carrying excess mass, applied only when actual weight exceeds ideal. For underweight patients the formula uses actual weight directly, because reduced muscle mass genuinely limits capacity. For patients under 30, age 30 is substituted.

On the cohort: the small, all-male, single-occupation derivation sample (and the extrapolated female equations) is the most frequent — and fair — criticism of this equation. Its durability rests on two things: the obesity-aware structure above, and the fact that its predictions closely track far larger, randomly sampled modern cohorts (see Reported accuracy, below).

SHIP / Gläser (cycle)

From the Study of Health in Pomerania, a large, randomly sampled healthy northeast German population (577 men and 626 women completing CPET) that deliberately included healthy obese subjects (~24% with BMI >30) and current smokers. **Among all the equations, SHIP and Hansen/Wasserman give the most similar predictions across the full age, height, and BMI range**.

Peak VO_2 in L/min:

> **MEN** PeakVO2 = −0.069 + 0.01402×height + 0.00744×weight + 0.00148×age − 0.0002256×age^2
> **WOMEN** PeakVO2 = −0.588 + 0.00913×height + 0.02688×weight − 0.01133×age − 0.00012×weight^2

Jones (cycle)

From 100 healthy Canadian adults. Two forms exist: **Jones 1** uses height and age but **not weight**; **Jones 2** adds weight. Jones 1 was endorsed as acceptable alongside Hansen/Wasserman by the 2003 ATS/ACCP statement, but because it omits weight it over-predicts in obese patients. Peak VO^2 in L/min:

> **MEN** Jones 1: PeakVO2 = −4.31 + 0.046×height − 0.021×age
> Jones 2: PeakVO2 = −3.76 + 0.034×height + 0.022×weight − 0.028×age
> **WOMEN** Jones 1: PeakVO2 = −4.93 + 0.046×height − 0.021×age
> Jones 2: PeakVO2 = −2.26 + 0.025×height + 0.010×weight − 0.018×age

Neder (cycle)

Derived from a randomly selected, rigorously screened sedentary Brazilian sample (drawn from >8,000 subjects). It uses age, weight, and height and yields values usually similar to, or slightly below, SHIP and Hansen/Wasserman. Peak VO^2 in L/min:

> **MEN** PeakVO2 = 0.702 + 0.0098×height + 0.0125×weight − 0.0246×age
> **WOMEN** PeakVO2 = 0.372 + 0.0074×height + 0.0075×weight − 0.0137×age

FRIEND (treadmill and cycle)

The Fitness Registry and the Importance of Exercise National Database (FRIEND) is the most contemporary large reference, built from a multi-site US cohort of healthy adults (>10,000; generalized equation derived on 7,617). It uses **actual** weight (no ideal-weight branching) and, uniquely among this set, supports both treadmill and cycle testing through a mode term. The widely cited generalized equation, Peak VO_2 in mL/kg/min:

> PeakVO2 = 45.2 − 0.35×age − 10.9×sex − 0.15×weight(lb) + 0.68×height(in) − 0.46×mode
> sex: male=1, female=2 mode: treadmill=1, cycle=2

For **cycle ergometry specifically** — the modality CPET-Insight most often interprets — setting the mode term to cycle and converting to metric units gives these sex-specific forms (peak VO^2 in mL/kg/min):

> **MEN** PeakVO2 = 33.38 − 0.35×age − 0.3307×weight + 0.2677×height
> **WOMEN** PeakVO2 = 22.48 − 0.35×age − 0.3307×weight + 0.2677×height

These cycle forms are algebraically equivalent to the generalized equation with the mode set to cycle, and they are the de Souza e Silva FRIEND equations printed in the Wasserman 6th-edition tables (where the column is mislabeled L/min — the values are in fact mL/kg/min). Note that the men's cycle intercept is 33.38; the value 33.8 sometimes seen is the treadmill intercept and should not be applied to cycle tests. Confirm which FRIEND variant a report uses before comparing percent-predicted across labs. A 2026 FRIEND extension models lean body mass and body-fat percentage (from NHANES equations) to improve calibration in obese patients.

Comparison: strengths, limitations, and best-fit populations

Part of the difference between equations reflects the healthy populations they were derived from — their size, fitness, body composition, and geography.

Equation	Derivation cohort	Strengths	Limitations	Best-fit populations
Hansen / Wasserman *cycle*	77 healthy men (mean age 54), S. California shipyard workers; cycle. Women's eq. added later (Hansen, 2001)	Handles obesity via ideal weight + excess-mass cost; decades of clinical use; ATS/ACCP-endorsed; tracks the large SHIP sample closely	Small (n=77), all-male, single-occupation derivation cohort; women's eq. extrapolated; cycle-derived; older sample	Generally healthy/untrained adults, including overweight/obese; cycle ergometry
SHIP / Gläser *cycle*	Large random German general-population sample; ~1,200 completed	Population-based random sampling; rigorous methods; closely matches Wasserman; smoker/β-blocker variants	European (German) cohort; cycle only; less familiar to US clinicians	Western general-population adults; strong second opinion alongside Wasserman
Jones 1 / Jones 2 *cycle*	100 Canadian adults	Simple; Jones 1 ATS/ACCP-acceptable; long track record	Small cohort; Jones 1 omits weight (over-predicts in obese); largest divergence from other equations	Lean, average-build adults; Jones 2 preferred if Jones used
Neder *cycle*	Random screened sedentary Brazilian sample (from >8,000)	Random sampling of sedentary adults; uses age/height/weight; close to SHIP/Wasserman	Smaller sample; values slightly low; South American cohort	Sedentary general-population adults; useful cross-check
FRIEND *treadmill + cycle*	>10,000 healthy US adults (contemporary)	Large modern cohort; treadmill AND cycle; newer lean-body-mass form improves obesity calibration	Uses actual weight (denominator inflation risk in older forms); variant ambiguity across software	Treadmill testing; contemporary US populations; fitness settings

Reported accuracy of each equation

For a reference equation, the primary accuracy criterion is **calibration** — how closely predicted values match measured values in a **healthy, untrained general population**, the very people the equation is meant to describe. Outcome-discrimination data (how well percent-predicted separates mortality or surgical risk) come from **disease cohorts** and are a useful but **secondary** check; they confirm an equation behaves sensibly, but they are not the basis for choosing a normal-value standard. Both are summarized below.

Equation	Reported accuracy / validation findings	Calibration in obesity
Hansen / Wasserman	Derived on a small cohort (77 men) — its main methodological criticism — yet its predictions are the most concordant with SHIP, the large random general-population reference, across age/height/BMI (mean absolute difference ~0.12 L/min). Supportive disease-cohort data: **highest discrimination for all-cause mortality in a 2024 head-to-head (AUC 0.812 vs FRIEND 0.796, Brazilian 0.753; WH vs Brazilian P=0.018)**, and %Predicted (WH) outperformed weight-indexed VO_2 for pre-lobectomy risk.	Good across most of the BMI range via the ideal-weight design; the simple weight term can distort at BMI extremes (the motivation for the 2026 lean-body-mass FRIEND work). Overestimates in East Asian cohorts.
SHIP / Gläser	Derived and internally validated on a large random general-population sample; predictions track Hansen/Wasserman most closely of any pair (~0.12 L/min). **%Predicted (SHIP) also outperformed weight-indexed VO_2 for surgical risk stratification**.	Robust — cohort deliberately included healthy obese subjects; quadratic weight term models heavier patients well.
Jones 1 / Jones 2	Largest divergence from the other equations (Jones 1 vs Jones 2 mean absolute difference ~0.45 L/min). Jones 1 systematically high where weight matters.	Poor for Jones 1 (no weight term)-over-predicts in obese; Jones 2 better but from a small cohort.
Neder	Small, consistent differences from SHIP and Hansen/Wasserman (~0.16 L/min); regarded as a reasonable Western general-population reference.	Adequate — includes a weight term; values run slightly low overall.
FRIEND	Large contemporary derivation and validation. In a heart-failure (disease) cohort, slightly better outcome discrimination than WH (AUC 0.74 vs 0.72; P=0.03) but yields markedly higher %Predicted (66±30% vs 58±25%). Comparable to WH for general-population mortality. Over predicts peak values for men in their 20's (elite cyclists in this age group).	Older forms use actual weight and can under-state the deficit in obesity; the 2026 lean-body-mass/body-fat FRIEND form is specifically better calibrated across BMI than Wasserman.

Bottom line on accuracy: no equation is uniformly "most accurate" for the healthy general population. ***Hansen/Wasserman and SHIP are the most concordant general-population references and the most broadly validated****; FRIEND offers a slight edge in some disease cohorts and adds treadmill capability; population-specific equations outperform all Western equations in East Asian populations.*

Where things stand now: 2021–2026

The most important recent development is a **negative** result that validates a cautious, lab-matched approach. In 2026 the European Respiratory Society / Global Lung Function Initiative CPET Task Force assembled data on 5,956 **healthy** individuals aged 6–83 across 17 sites in Europe, the Americas, and Asia, aiming to derive the first all-age **global** reference equation for Peak VO_2. It could not: heterogeneity in equipment, protocols, and peak-averaging methods between sites was too large, and controlling for these factors did not make the model reliable. The Task Force concluded that a single universal equation does not yet exist and called for **prospectively standardized, centrally analyzed data**. For now, the practical implication is unchanged from the textbook's advice, select a well-validated equation matched to your healthy reference population and methodology, and apply it consistently.

Three other threads define the current landscape:

1. **Obesity calibration** is the main frontier: a 2026 FRIEND analysis used NHANES lean-body-mass and body-fat estimates to build equations better calibrated than Wasserman across the BMI spectrum, reflecting a broader shift toward body-composition-aware prediction.
2. **Percent-predicted continues to outperform raw mL/min/kg**: a 2024 surgical study found percent-predicted Peak VO_2 (by Wasserman/Hansen or SHIP) stratified post-lobectomy (lung) risk where weight-indexed VO_2 did not.
3. **Population specificity** is now well documented — Caucasian-derived equations overestimate Peak VO_2 in East Asian cohorts, prompting dedicated Chinese (e.g., PUTH, 2025) and other national equations.

CPET-Insight's position: why we default to Wasserman

CPET-Insight uses the Hansen/Wasserman equation as its default reference for Peak VO_2. This is a considered choice:

A reference equation must describe the healthy, untrained general population. Its job is to answer one question: what Peak VO_2 would a normal, relatively sedentary person of this sex, age, height, and weight be expected to reach? Hansen/Wasserman is derived from, and intended for, exactly that population — healthy untrained adults across a wide range of body sizes — which is why its predicted values transfer cleanly to the mixed general-clinical referrals we see. Equations tuned to, or evaluated only within, a specific disease group answer a different question and are not appropriate as a general normal-value standard.

It is the most widely used and best understood standard in clinical CPET. It is embedded in interpretive literature, recognized by referring cardiologists and pulmonologists, and endorsed (with Jones 1) by the ATS/ACCP. Using it keeps our reports legible to the broadest clinical audience and comparable with the published evidence base.

It handles real-world body habitus. Our referral population, like most clinical CPET populations, includes many overweight, obese, and morbidly obese patients. The ideal-weight design with an explicit oxygen cost for excess mass keeps Hansen/Wasserman stable across the BMI range, where weight-blind equations fail.

Its accuracy holds up where it counts — despite a small original cohort. We acknowledge the principal criticism: the equation was derived from only 77 men, with the female equations added later. What has kept it credible is external concordance. Against large, rigorously sampled general-population cohorts it is the most concordant equation, tracking SHIP — a random sample of more than 1,200 adults — more closely than any other pair. The disease-cohort outcome studies are consistent with this: where FRIEND edges it, the margin is small and comes with substantially higher percent-predicted values that shift impairment thresholds, particularly with men in their 20' and higher BMI (not weight corrected).

It consists of 21 years of practice. Across 21 years of clinical CPET interpretation at MET-TEST, Hansen/Wasserman proved consistently useful and clinically coherent across the full spectrum of general-population referrals; the kind of accumulated, real-world validation that complements the published comparisons.

We fully support customers who prefer other equations. CPET-Insight reporting accommodates FRIEND and other reference sets on request. FRIEND is a reasonable default for treadmill-based programs and contemporary US populations; SHIP, Neder, and Inbar are sound Western general-population alternatives; and population-specific equations are appropriate where validated. Our only firm requirements are that the equation matches the exercise mode and that **serial tests on the same patient use the same equation**, so that change over time reflects physiology rather than a change in reference standard.

Practical recommendations

Match the equation to the **exercise mode** (cycle vs treadmill). Remember that these reference values describe **relatively sedentary, untrained adults**: expect higher values in habitual exercisers and athletes, and lower values for deconditioned and disease populations. Use a **lower limit of normal** consistent with your interpretive framework (CPET-Insight treats 85% of predicted as the lower bound of the normal range; the textbook's broader guidance places the statistical lower limit near 75% of the mean). For patients aged 18–29, substitute age 30. Account for **altitude** (roughly 5% lower at ~1,600 m; 15–20% lower at ~3,200 m) and for **β-blockade**, which can reduce Peak VO_2. When a patient sits at the extremes of age, height, or weight, compare two or more equations before calling a value abnormal.

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