Cardiopulmonary exercise testing for peak oxygen uptake (VO2peak) is widely used to evaluate severity, pathophysiology and prognosis in patients with chronic heart failure (CHF). A VO2peak ≥14 (or 12 with β-blocker) ml/kg/min is associated with increased mortality and is a key criterion for cardiac transplant listing. A symptom-limited exercise test, however, may elicit a VO2peak lower than the maximum physiological limit (VO2max); the latter commonly “confirmed” using the secondary criterion of respiratory exchange ratio (RER) >1.05. RER, however, is sensitive to the test format. We, therefore, determined if a ramp-incremental (RI) step-exercise (SE) or RISE test could determine VO2max in CHF patients without using RER, by satisfying the criterion that two different work rates are terminated at the same VO2peak. Twenty-one male CHF patients (NYHA class I: n=3, II: n=16, and III: n=1) initially performed a modified Bruce treadmill test. Patients then completed a symptom-limited RISE95 cycle ergometer test in the format: RI (4–18 W/min; ~10 min); 5-min recovery (10 W); SE (95% of peak RI work rate). Thirteen of these patients also performed RISE95 tests using slow (RI 3–8 W/ min; ~15 min) and fast (RI 10–30 W/min; ~6 min) ramp rates. VO2 and RER were measured breath-by-breath by a mass spectrometer and turbine (MSX, NSpire, UK). Peak VO2 and RER were compared within-subjects, between RI and SE, by unpaired t test of the final 12 breaths of exercise. This approach allowed VO2max and its associated 95% confidence limits to be estimated. VO2peak was similar (p>0.05) in treadmill and cycle exercise (mean±SD: 16.2±2.7 vs 15.0±3.2 ml/kg/min, n=20, respectively), despite RER being greater in cycling (1.08±0.12 vs 1.15±0.09; p<0.05). As a group, VO2peak was similar (p>0.05) between RI and SE (mean±SD: 14.6±5.2 vs 14.9±3.2 ml/kg/min, n=21). A within-subject comparison, however, revealed that the VO2max criterion was met in 14 of 21 patients (measurement sensitivity range 0.6–3.8 ml/kg/min), despite RER being >1.05 in the remaining 7 (1.16±0.09). There was no effect of ramp rate on VO2peak (p>0.05), however RER was greater (p<0.05) in the fast ramp (1.24±0.09) compared to the slow (1.12±0.06). The single-visit RISE95 test incorporating incremental-and step- exercise phases, each to the volitional limit, was well tolerated by CHF patients: The SE phase was contraindicated in only 3 of the 47 tests. The RISE95 detected VO2max in 14 of 21 patients with a sensitivity of ~10% (ie, similar to healthy subjects), and without the need for secondary criteria or incidence of false-positive. In contrast, the end-exercise RER was sensitive to both modality and ramp rate and provided a false-positive for VO2max attainment in every incidence. Therefore, the RISE95 protocol provides a robust measure of VO2max in CHF patients, to within an individually-defined CI without dependence on secondary criteria.

Rapid adaptation of pulmonary oxygen uptake (VO2) at exercise onset reduces the reliance on limited anaerobic energy stores and is associated with increased exercise tolerance. These VO2 kinetics, however, are slow in patients with chronic heart failure (CHF). This could be due to limitations in the control of muscle O2 consumption and/O2 delivery. Recent evidence in CHF of a transient overshoot in microvascular deoxygenation at exercise onset supports the latter. As prior exercise is known to increase muscle blood flow in healthy individuals, we examined whether it could attenuate the fall in microvascular deoxygenation and speed VO2 kinetics on transition to moderate exercise in CHF patients. Thirteen CHF patients (NYHA class I: n=3, II: n=9, and III: n=1) performed a ramp test on a cycle ergometer for estimation of lactate threshold (LT) and VO2max. Patients subsequently repeated two 6-min moderate-intensity exercise transitions (bout 1, bout 2) from rest to 90%LT, separated by 6-min of rest. Measurements included breath-by-breath VO2 using a turbine and mass spectrometer (MSX, NSpire, UK), and tissue oxygenation index (TOI) of the vastus lateralis by spatially resolved near-infrared spectroscopy (NIRO200, Hamamatsu, Japan). The exponential time constant (τ) for TOI and phase II VO2 were estimated using non-linear least-squares regression. The tVO2/τTOI, or “kinetic index”, was taken to reflect the relative matching of muscle oxygenation to its instantaneous requirement. LT and VO2max were 9.9±1.7 (mean±SD) and 15.0±5.2 ml/kg/min, respectively. Prior exercise increased resting TOI by 10±3% (p<0.05), attenuated the transient overshoot in muscle deoxygenation by ~50% (p<0.05) and slowed the rate of deoxygenation in the transient (τTOI: 10±1 vs 21±3 s; p<0.05). Both tVO2 (<40 vs 39±18 s; p<0.05) and the kinetic index (4.5±1.8 vs 2.2±0.9; p<0.05) were reduced following prior exercise. tVO2 was well correlated to the kinetic index (R²=0.92) in bout 1. However, although a lower tVO2 was typically reflected in a reduced kinetic index in bout 2, VO2 kinetics remained slowed in 4 patients. These patients had a higher NYHA class (2.3±0.5 vs 1.6±0.5; p=0.06) and greater initial tVO2 (62±17 vs 33±9 s; p<0.05) than the others. In CHF prior moderate-intensity exercise improved the dynamic matching of muscle oxygenation to its instantaneous requirement and speeded VO2 kinetics in all patients. This suggests that slow VO2 kinetics in CHF are due, at least in part, to a dynamic limitation in O2 delivery. However, this approach revealed an apparent limitation in the control of muscle O2 consumption in the most severe patients, which was only partly ameliorated by improving O2 delivery. Nevertheless, these findings suggest that an acute intervention to improve muscle oxygenation can increase aerobic energy provision on transition to exercise in CHF patients.