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# A Reference Equation for Normal Standards for $VO_2$ Max: Analysis from the Fitness Registry and the Importance of Exercise National Database (FRIEND Registry)

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ABSTRACT

Existing normal standards for maximal oxygen uptake ($VO_2$ max) are problematic because they tend to be population specific, lack normal distribution and portability, and are poorly represented by women. The objective of the current study was to apply the Fitness Registry and the Importance of Exercise: A National Data Base (FRIEND) Registry to improve upon previous regression formulas for normal standards for $VO_2$ max using treadmill testing. Maximal treadmill tests were performed in 7783 healthy men and women (20–79 years; maximal RER >1.0) from the FRIEND registry and a separate validation cohort of 1287 subjects. A regression equation for $VO_2$ max was derived from the FRIEND registry and compared to the validation cohort and two commonly used equations (Wasserman and European). Age, gender, and body weight were the only significant predictors of $VO_2$ max (multiple $R = 0.79$, $R^2 = 0.62$, $p < 0.001$). The equation for predicting $VO_2$ max was:

$$VO_2\ \text{max}\left(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}\right) = 79.9 - (0.39 \times \text{age}) - (13.7 \times \text{gender}\ [0 = \text{male}; 1 = \text{female}]) - (0.127 \times \text{weight}\ [\text{lbs}]).$$

Marked differences were observed in percentage predicted $VO_2$ max achieved between commonly used reference equations, particularly among women, overweight and obese subjects. In the validation sample, the FRIEND equation closely paralleled measured $VO_2$

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max, with the validation group yielding a percent predicted $VO_2$ max of 100.4% based on the FRIEND equation. An equation for age-predicted $VO_2$ max derived from the FRIEND registry provided a lower average error between measured and predicted $VO_2$ max than traditional equations, and thus may provide a more suitable normal standard relative to traditional equations.
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## Contents



The measurement of exercise capacity has numerous clinical applications, including risk stratification, evaluation of the efficacy of therapy in patients with cardiovascular disease (CVD) or pulmonary disease, and the assessment of disability.[1] In recent years, a growing body of data has demonstrated that fitness level powerfully predicts risk for adverse events across the spectrum of health and disease; in many studies, fitness has been shown to outperform the traditional risk factors in terms of health outcomes.[1–4] The gold standard expression of cardiorespiratory fitness (CRF) is maximal oxygen uptake ($VO_2$ max), using ventilatory gas exchange techniques.[5–7] An individual's $VO_2$ max should initially be considered in terms of what is normal for a given individual if he or she was healthy. It is well known that $VO_2$ max declines with age and that higher values are observed in men compared with women.[6–10] Therefore, it is critical to have reference values for comparison when assessing $VO_2$ max. However, determining what constitutes a normal standard for gender and age is complicated by several factors, including definition of normalcy, genetics, body mass, and population heterogeneity.[6,11–15] While there have been a number of studies in this area, few samples have been large enough to firmly establish "normal standards".[6,15] In addition, all are specific to the population from which they were drawn, and there have been comparatively few women included in these studies. Although the equations developed by Hansen, Sue and Wasserman (commonly termed the Wasserman equations),[14] are widely used, they were derived from a relatively limited sample and often do not function well in populations other than middle-aged, normal weight males (e.g., overweight, the elderly, or females).[16–19]

The need for better reference standards for $VO_2$ max was recognized in a 2013 policy statement by the American Heart Association (AHA).[15] The Fitness and the Importance of Exercise: A National Data Base (FRIEND) registry was initiated to enhance the value of CRF across environments, including the clinical setting and workplace as well as the public, to better inform national policy efforts on physical fitness, activity and health. While reference standards were recently described using the FRIEND registry based on age decades,[20,21] there remains a need for a widely applicable regression equation for fitness standards appropriate for men and women across the spectrum of age. The FRIEND initiative provided an ideal opportunity to develop such an equation given that it includes a diverse sample of healthy men and women in the United States (US) whose exercise tests met objectively verified criteria for maximal effort. The purpose of the current report was to apply the FRIEND data registry to improve upon previous regression formulas for age- and gender-expected standards for $VO_2$ max using treadmill testing.

## Methods

The procedures used for acquiring and managing the data for the FRIEND registry have been previously reported.[15] In brief, laboratories determined by the advisory board to use valid and reliable calibration and cardiopulmonary exercise test (CPX) procedures administered by experienced personnel were invited to be considered for inclusion in the FRIEND Registry. Although there were some variations in laboratory equipment, protocols, and procedures defining $VO_2$ max, the characteristics of all participating CPX laboratories are consistent with recommendations outlined in recently published guidelines.[5,22] Local institutional review board approval for participation in the FRIEND Registry was obtained by each