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Reference Standards for Cardiorespiratory Fitness Measured With Cardiopulmonary Exercise Testing: Data From the Fitness Registry and the Importance of Exercise National Database

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Abstract

Objective: To develop standards for cardiorespiratory fitness by establishing reference values derived from cardiopulmonary exercise testing (CPX) in the United States.

Patients and Methods: Eight laboratories in the US experienced in CPX administration with established quality control procedures contributed data from January 1, 2014, through February 1, 2015, from 7783 maximal (respiratory exchange ratio, ≥1.0) treadmill tests from men and women (aged 20-79 years) without cardiovascular disease (CVD) to the Fitness Registry and the Importance of Exercise: A National Data Base (FRIEND). Percentiles of maximal oxygen consumption ($\dot{V}O_{2max}$) for men and women were determined for each decade from 20 years of age through 79 years of age. Comparisons of $\dot{V}O_{2max}$ were made to reference data established with CPX data from Norway and to US reference data established without CPX measurements.

Results: There were significant differences between sex and age groups for $\dot{V}O_{2max}$. In FRIEND, the 50th percentile $\dot{V}O_{2max}$ of men and women aged 20 to 29 years decreased from 48.0 and 37.6 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ to 24.4 and 18.3 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ for ages 70 to 79 years, respectively. The rate of decline in this cohort during a 5-decade period was approximately 10% per decade.

Conclusion: These are the first cardiorespiratory fitness reference data using measures obtained from CPX in the United States. FRIEND can be used to provide a more accurate interpretation of measured $\dot{V}O_{2max}$ from maximal exercise tests for the US population compared with previous standards on the basis of workload-derived estimations.

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An increasing body of data have revealed that cardiorespiratory fitness (CRF) powerfully predicts outcomes across the spectrum of health and disease.[1-4] CRF can be directly measured as maximal oxygen consumption ($\dot{V}O_{2max}$) from a cardiopulmonary exercise testing (CPX) or is often estimated as the exercise capacity (maximal work rate) from an exercise test. Indeed, during the last 2 decades, many epidemiologic studies have reported that CRF is a more powerful predictor of risk for adverse outcomes than traditional risk factors, including hypertension, lipid abnormalities, smoking, physical inactivity, obesity, and diabetes mellitus.[2,5,6] Low CRF, typically defined as the lowest quartile or quintile on an exercise test, is associated with 2- to 5-fold increases in CVD or all-cause mortality, independent of other CVD risk factors.[4-7] Importantly, relatively small improvements in CRF (such as 1 metabolic equivalent [MET]) have been associated with considerable reductions in mortality (10% to 25%).[1,3-8] These findings have led health authorities to recommend, and some US health systems to mandate, physical activity assessment and counseling as part of clinical encounters.[9] However, despite the fact that low CRF is one of the most important determinants of health outcomes, it is often neglected in the risk paradigm in favor of risk markers more familiar to most

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TABLE 1. Descriptive Characteristics of the FRIEND Cohort[a,b]

	Age group (y)					
Characteristic	20-29 (n = 513 men and 410 women)	30-39 (n = 963 men and 608 women)	40-49 (n = 1327 men and 843 women)	50-59 (n = 1078 men and 805 women)	60-69 (n = 593 men and 408 women)	70-79 (n = 137 men and 98 women)
Men						
Age, y	24.6±2.7	34.9±2.8	44.4±2.8	54.0±2.7	63.7±2.7	72.7±2.4
Height (cm)	179.6±7.4	178.8±6.9	178.8±6.6	178.1±8.9	177.3±6.9	175.5±6.9
Weight (kg)	82.6±16.6	82.6±16.3	86.3±16.1	88.1±17.2	87.1±16.4	83.9±15.0
Women						
Age, (y)	24.8±2.6	34.9±2.8	44.6±2.9	54.2±2.8	63.6±2.6	73.1±2.2
Height (cm)	166.1±7.1	165.4±6.4	164.3±6.6	163.4±6.6	162.6±6.1	162.1±5.8
Weight (kg)	66.3±15.4	71.4±19.0	74.0±19.6	76.9±18.4	77.2±16.2	74.8±15.9

[a]FRIEND = Fitness Registry and the Importance of Exercise National Database.
[b]Data are presented as mean ± SD.

clinicians who are likely to focus on conditions treatable with drugs or invasive procedures.[9-12]

Given the importance of CRF in estimating health risk, it is essential to have accurate reference values to know what constitutes a "normal" value. When reviewing results of an exercise test, an individual's CRF should initially be considered in terms of what is normal for a given individual if he or she were healthy. This is critical because CRF decreases with age, and higher values are generally observed in men. Thus, a given CRF level for a 40-year-old man has a significantly different meaning than the same CRF for an elderly woman. Knowing an individual's exercise capacity relative to their peers will not only help to optimize risk stratification but also can facilitate discussions between health care professionals and patients regarding health risks, provide a baseline for improving CRF, and provide support for physical activity counseling. Currently, the only widely cited reference data in the United States are derived from the Cooper Clinic, which uses estimated CRF values that are calculated from treadmill speed and grade.[13]

The 2003 Statement on CPX by the American Thoracic Society and the American College of Chest Physicians recognized that having normal reference values "is critical to any interpretative scheme."[14] However, they recognized that at the time, no clear set of standards existed from CPX. Paap and Takken[15] performed a systematic review of the literature on reference values for CPX and noted that most studies had small sample sizes and used cycling for the mode. They reported that only 4 studies met their criterion for high quality, with only 2 of these using treadmill testing. Both the American Thoracic Society/American College of Chest Physicians statement and the Paap and Takken review provide summaries of attempts to derive normative CRF regression equations from the criterion standard measurement, CPX, to predict CRF on the basis of age, sex, and, in some cases, body mass. The primary limitation of currently available US equations using this approach is the relatively small cohorts assessed with limited diversity. In addition, all are specific to the population from which they were drawn. For example, equations published by Hansen, Sue, and Wasserman are the most widely used standards for directly measuring $\dot{V}O_{2max}$; however, they were derived from a small group (n=77) of men who underwent cycle testing combined with a sample of 295 women and men who performed treadmill tests from a previous study.[16,17] Recently, 2 studies provided some reference values using CPX in Norwegian cohorts.[18,19] The latter analysis is considered a significant advance in the field given that a much larger cohort was analyzed (n=3816) across the lifespan. Nevertheless, applicability of the Norwegian CRF reference values to individuals in the United States is uncertain.

The clear need for developing reference standards for CRF in the United States was recognized in a policy statement by the American Heart Association.[20] An independent group was formed with preliminary funding to establish a CRF registry office and advisory board (members listed in Acknowledgments).