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BRIEF REPORT

Reference Standards for Cardiorespiratory Fitness Measured With Cardiopulmonary Exercise Testing Using Cycle Ergometry: Data From the Fitness Registry and the Importance of Exercise National Database (FRIEND) Registry

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Abstract

The importance of cardiorespiratory fitness (CRF) is well established. This report provides newly developed standards for CRF reference values derived from cardiopulmonary exercise testing (CPX) using cycle ergometry in the United States. Ten laboratories in the United States experienced in CPX administration with established quality control procedures contributed to the "Fitness Registry and the Importance of Exercise: A National Database" (FRIEND) Registry from April 2014 through May 2016. Data from 4494 maximal (respiratory exchange ratio, $\geq$1.1) cycle ergometer tests from men and women (20-79 years) from 27 states, without cardiovascular disease, were used to develop these references values. Percentiles of maximum oxygen consumption (VO_{2max}) for men and women were determined for each decade from age 20 years through age 79 years. Comparisons of VO_{2max} were made to reference data established with CPX data from treadmill data in the FRIEND Registry and previously published reports. As expected, there were significant differences between sex and age groups for VO_{2max} ($P<.01$). For cycle tests within the FRIEND Registry, the 50th percentile VO_{2max} of men and women aged 20 to 29 years declined from 41.9 and 31.0 mLO_2/kg/min to 19.5 and 14.8 mLO_2/kg/min for ages 70 to 79 years, respectively. The rate of decline in this cohort was approximately 10% per decade. The FRIEND Registry reference data will be useful in providing more accurate interpretations for the US population of CPX-measured VO_{2max} from exercise tests using cycle ergometry compared with previous approaches based on estimations of standard differences from treadmill testing reference values.

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A recent scientific statement from the American Heart Association presented a strong case for assessing cardiorespiratory fitness (CRF) as a clinical vital sign.[1] This statement will undoubtedly lead to efforts to increase the assessment of CRF. The criterion standard method for assessing CRF is a maximal exercise test with cardiopulmonary measurements (cardiopulmonary exercise testing [CPX]). Recently, based on a policy statement by the American Heart Association, the "Fitness Registry and the Importance of Exercise: A National Database" (FRIEND) Registry established the first set of normative CRF standards for test interpretation from maximal exercise treadmill tests.[2,3]

The treadmill is 1 of the 2 primary modes used for exercise testing, the other being the cycle ergometer. Cycle ergometers have several advantages over treadmills, including less expense, fewer space requirements, more portability, and safety. In addition, cycle ergometry is a feasible alternative to treadmill testing in obese individuals, or those who have orthopedic, peripheral vascular, and/or neurologic limitations that may preclude treadmill testing.[4] However, maximum oxygen consumption values (VO_{2max}) are approximately 10% to 20% lower when using a cycle

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ergometer compared with a treadmill.[5] These differences in VO_{2max} depend largely on an individual's physical conditioning, leg strength, and primary mode of training.[4] Presently, interpretation of VO_{2max} from cycle testing is based on early work with relatively small sample sizes done by Hansen et al[6] in the United States and from others in Canada and Europe as summarized by Myers.[7]

Given the potential interindividual differences between treadmill and cycle ergometer VO_{2max} values, it is important to establish current CRF reference standards for cycle ergometer exercise testing. Therefore, the purpose of this report was to improve interpretations of VO_{2max} from cycle testing by developing normative reference standards derived from a more comprehensive sample of CPX done in the United States.

METHODS

The procedures used for acquiring and managing the data for the FRIEND Registry have been previously reported.[2] Briefly, laboratories determined by the CRF advisory board to use valid and reliable calibration and CPX testing 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_{2max} (using an average of data during the final 30-60 seconds of the CPX), the characteristics of all participating CPX laboratories are consistent with recommendations provided in recently published guidelines.[8,9] Local institutional review board approval for participation in the FRIEND Registry was obtained by each participating CPX laboratory to submit deidentified, coded data to the data coordinating center at Ball State University, which then forwarded these data to the core CPX laboratory housed at the University of Illinois-Chicago. Institutional review board approval for the core CPX laboratory was also obtained at the University of Illinois-Chicago. These CPX laboratories contributed their data to the FRIEND Registry from April 2014 through May 2016. Data from each CPX laboratory were reviewed for uniformity and to ensure data points were within expected normal ranges by both the coordinating center and the core laboratory before merging into the FRIEND Registry database.

Cohort

The current analysis includes 4494 tests from the 10 participating CPX laboratories (see Acknowledgments) with geographical representation from 27 states including Indiana, Louisiana, North Carolina, Oregon, Pennsylvania, Tennessee, Texas, and 1 lab with tests from multiple states. Any subject identified as having a preexisting diagnosis of cardiovascular disease (CVD) was excluded from the current analysis. Inclusion criteria were as follows: CPX data for those free from any known CVD at the time of testing; (2) age 20 years or more; (3) maximal exercise test performed on a cycle ergometer; and (4) peak respiratory exchange ratio value of 1.10 or more.[10]

Statistical Analyses

Continuous data were reported as mean and SD, whereas categorical data were reported as frequencies and percentages. Analysis of variance was used to compare differences in VO_{2max} values between sexes and across age groups. When significant differences were detected by analysis of variance, the Tukey test was used for post hoc analysis. The SPSS 24.0 (IBM) statistical software package was used for all analyses. All tests with a P value of less than .05 were considered statistically significant.

RESULTS

The FRIEND cohort for this report included 1717 tests on men and 2777 on women, with ages ranging from 20 to 79 years. Descriptive characteristics of the cohort, by sex and in 10-year age groups, are listed in Table 1.

Peak responses from CPX using a cycle ergometer are presented in Table 2A. Relative and absolute VO_{2max} values from 2 previous studies from Lithuania (20-59 years) and Finland (55-74 years) are presented in Table 2B for comparison.[2,11,12] Because a typical approach for determining normative values for cycle testing has been to use a standard lowering of 10% to 20% from treadmill reference values, we have also included a comparison to values predicted as 85% of the FRIEND treadmill reference standards in this table.[2,5] There were significant differences ($P<.01$) between men and women in maximal workload (watts), absolute VO_{2max} (L/min), and relative VO_{2max} (mLO_2/kg/min), with

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