

Age-Predicted Maximal Heart Rate Revisited

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- OBJECTIVES** We sought to determine a generalized equation for predicting maximal heart rate (HR_{max}) in healthy adults.
- BACKGROUND** The age-predicted HR_{max} equation (i.e., $220 - \text{age}$) is commonly used as a basis for prescribing exercise programs, as a criterion for achieving maximal exertion and as a clinical guide during diagnostic exercise testing. Despite its importance and widespread use, the validity of the HR_{max} equation has never been established in a sample that included a sufficient number of older adults.
- METHODS** First, a meta-analytic approach was used to collect group mean HR_{max} values from 351 studies involving 492 groups and 18,712 subjects. Subsequently, the new equation was cross-validated in a well-controlled, laboratory-based study in which HR_{max} was measured in 514 healthy subjects.
- RESULTS** In the meta-analysis, HR_{max} was strongly related to age ($r = -0.90$), using the equation of $208 - 0.7 \times \text{age}$. The regression equation obtained in the laboratory-based study ($209 - 0.7 \times \text{age}$) was virtually identical to that obtained from the meta-analysis. The regression line was not different between men and women, nor was it influenced by wide variations in habitual physical activity levels.
- CONCLUSIONS** 1) A regression equation to predict HR_{max} is $208 - 0.7 \times \text{age}$ in healthy adults. 2) HR_{max} is predicted, to a large extent, by age alone and is independent of gender and habitual physical activity status. Our findings suggest that the currently used equation underestimates HR_{max} in older adults. This would have the effect of underestimating the true level of physical stress imposed during exercise testing and the appropriate intensity of prescribed exercise programs. (J Am Coll Cardiol 2001;37:153-6) © 2001 by the American College of Cardiology

Maximal heart rate (HR_{max}) is one of the most commonly used values in clinical medicine and physiology. For example, a straight percentage of HR_{max} or a fixed percentage of heart rate reserve ($HR_{max} - \text{heart rate at rest}$) is used as a basis for prescribing exercise intensity in both rehabilitation and disease prevention programs (1,2). Moreover, in some clinical settings, exercise testing is terminated when subjects reach an arbitrary percentage of their age-predicted maximal heart rate (e.g., 85% of HR_{max}) (3). Maximal heart rate also is widely used as a criterion for achieving peak exertion in the determination of maximal aerobic capacity (1,4,5).

Because maximal exercise testing is not feasible in many settings, HR_{max} is often *estimated* using the age-predicted equation of $220 - \text{age}$. However, the validity of the age-predicted HR_{max} equation has not been established, particularly in a study sample that included an adequate number of older adults (e.g., >60 years of age). The latter limitation is crucial in that older adults demonstrate the highest prevalence of cardiovascular and other chronic diseases. As such, this is the most prevalent population undergoing diagnostic exercise testing, representing a key clinical target for exercise prescription. Importantly, older adults are a population in which there is often a reluctance or an inability to measure HR_{max} directly, owing to concerns

related to the physiologic stress imposed by strenuous exercise. Thus, ironically, the $220 - \text{age}$ HR_{max} prediction equation is used in this population more than in any other.

Accordingly, the aim of the present study was to determine an equation for predicting HR_{max} in healthy, non-medicated humans ranging widely in age. To address this aim, we first used a meta-analytic approach in which group mean HR_{max} values were obtained from the published data. Subsequently, we cross-validated the newly derived equation in a well-controlled, laboratory-based study. With each approach, we attempted to establish the generalizability of the equation by determining whether gender or habitual physical activity status exerted a significant modulatory influence on the HR_{max} -age relation.

METHODS

Meta-analytic study. Meta-analysis is a set of quantitative procedures for systematically integrating and analyzing the findings of previous research. Meta-analysis in the present study was conducted as described previously in detail by our laboratory (6). As an initial step, an extensive search of the published data was conducted to identify as many studies as possible in which HR_{max} was measured. Initially, this was done by using computer searches. In addition, extensive hand searching and cross-referencing were performed using bibliographies of already retrieved studies. The following criteria for inclusion were used: 1) English language studies published in peer-reviewed journals; 2) data on men and women reported separately; 3) at least five subjects per group; 4) only the most recently published results of a

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Abbreviations and Acronyms

HR_{max} = maximal heart rate
 $\dot{V}O_2$ = minute oxygen consumption

particular study group; 5) adult subjects; 6) maximal exertion documented by using objective criteria (5); and 7) only healthy (e.g., nonischemic electrocardiographic response), nonmedicated and nonsmoking groups. A list of reports included in the meta-analysis can be obtained from the authors upon request. Because the studies included in the meta-analysis used different terms to describe the aerobic exercise status of their subject groups, we classified and analyzed the groups into three arbitrarily defined categories: 1) endurance-trained, referring to regular performance of vigorous endurance exercise ≥ 3 times/week for over one year; 2) active, referring to occasional or irregular performance of aerobic exercise ≤ 2 times/week; and 3) sedentary, referring to no performance of any aerobic exercise. Data from treadmill and cycle ergometers were evaluated together and separately. There were no differences in the results between the two analyses. Therefore, data from both exercise modes were pooled and are presented together. This meta-analysis included a total of 351 studies involving 492 subject groups (161 female and 331 male groups) and 18,712 subjects. Because we have previously shown that weighted results by sample size were not significantly different from unweighted results (6), no weighting scheme was used in the present meta-analysis.

Laboratory-based study. Five-hundred fourteen subjects (237 men and 277 women) were studied (age range 18 to 81 years). All of the subjects were apparently healthy and free of overt coronary artery disease, as determined by a medical history questionnaire. Subjects >50 years of age were further evaluated by physical examination and by rest and maximal exercise electrocardiography ECG (3). None of the subjects smoked or used any medications other than hormone replacement (postmenopausal women). To eliminate the potentially confounding influence of severe obesity, only subjects with a body mass index <35 kg/m² were included. Two different groups were studied: endurance exercise-trained and sedentary. The endurance-trained subjects (n = 229) had been training for at least the past two years. The subjects in the sedentary group (n = 285) performed no regular physical exercise. Before participation, the subjects gave their written, informed consent to participate in this investigation. This study was reviewed and approved by the Human Research Committee at the University of Colorado at Boulder.

Maximal heart rate was determined by a continuous, incremental treadmill protocol, as previously described in detail by our laboratory (4). Heart rates were continuously monitored with electrocardiography. Minute oxygen consumption ($\dot{V}O_2$) also was measured using on-line, computer-assisted, open-circuit spirometry (4). After a warm-up

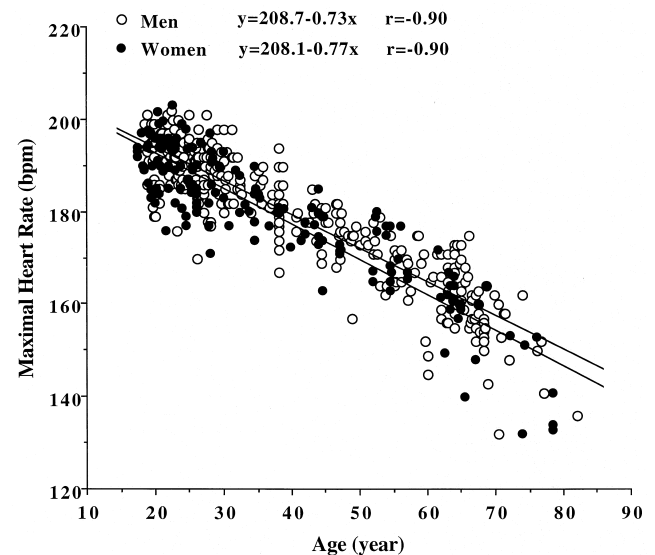


Figure 1. Relation between maximal heart rate (HR_{max}) (group mean values) and subject group age obtained from the meta-analysis.

period of 6 to 10 min, each subject ran or walked at a comfortable but brisk speed. The treadmill grade was increased 2.5% every 2 min until volitional exhaustion. At the end of each stage, the subjects were asked to rate their perception of effort using a Borg category scale (6 to 20 rating). Maximal heart rate was defined as the highest value recorded during the test. To ensure that each subject achieved maximal exertion, at least three of the following four criteria were met by each subject: 1) a plateau in $\dot{V}O_2$ with increasing exercise intensity (<100 ml); 2) a respiratory exchange ratio of at least 1.15; 3) a maximal respiratory rate of at least 35 breaths/min; and 4) a rating of perceived exertion of at least 18 units on the Borg scale (5).

Statistical analysis. Linear regression analyses were performed to determine the association among variables. In all cases, age was used as the predictor variable. Pearson product-moment correlation coefficients were used to indicate the magnitude and direction of relations among variables. The slopes of regression lines were compared using analysis of covariance. Forward stepwise multiple regression analyses were used to identify significant independent determinants for the age-related declines in HR_{max}. To do so, only those variables that had significant univariate correlations with HR_{max} (e.g., age, body mass) were entered in the model. All data were reported as the pooled mean value \pm SD. The statistical significance level was set, a priori, at $p < 0.01$ for all analyses.

RESULTS

Meta-analytic study. Figure 1 illustrates the decline in HR_{max} in men and women included in the meta-analysis. Maximal heart rate was strongly and inversely related to age in both men and women ($r = -0.90$). The rate of decline and the y intercepts were not different between men and women nor among sedentary ($211 - 0.8 \times \text{age}$), active

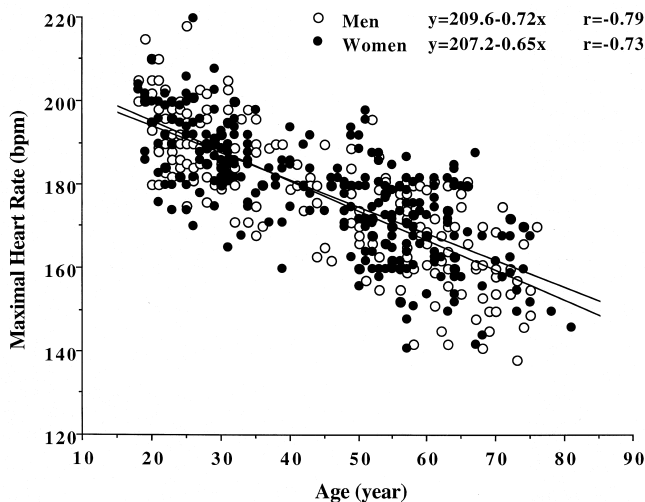


Figure 2. Relation between maximal heart rate (HR_{max}) and age obtained from the prospective, laboratory-based study.

($207 - 0.7 \times \text{age}$) and endurance-trained ($206 - 0.7 \times \text{age}$) subjects. The regression equation, when all the subjects were combined, was $208 - 0.7 \times \text{age}$. Stepwise regression analysis revealed that age alone explained $\sim 80\%$ of the individual variance in HR_{max} .

Laboratory-based study. The maximal respiratory exchange ratio (1.17 ± 0.06) and maximal rating of perceived exertion (19.1 ± 0.8) were not different across ages, suggesting consistently similar voluntary maximal efforts. The relation between HR_{max} and age obtained in the laboratory-based study is presented in Figure 2. Maximal heart rate was inversely related to age in both men and women. There was substantial variation in HR_{max} across the entire age range, with standard deviations ranging from 7 to 11 beats/min. The regression equation for HR_{max} ($209 - 0.7 \times \text{age}$) was virtually identical to that obtained from the meta-analysis. Again, no significant differences in the HR_{max} regression equation were observed between men and women or between sedentary ($212 - 0.7 \times \text{age}$) and endurance-trained ($205 - 0.6 \times \text{age}$) subjects.

DISCUSSION

The primary findings of the present study are as follows. First, a regression equation for estimating HR_{max} is $208 - 0.7 \times \text{age}$ in healthy adult humans, which is significantly different from the traditional $220 - \text{age}$ equation. Second, HR_{max} is predicted, to a large extent, by age alone and is independent of gender and physical activity status. These results were first obtained in a meta-analysis of previously published studies and then confirmed in a prospective, well-controlled, laboratory-based study. Our findings suggest that the prevailing equation significantly underestimates HR_{max} in older adults. This would have the effect of underestimating the true level of physical stress imposed during exercise testing, as well as the intensity of exercise programs that are based on HR_{max} -derived target heart rate prescriptions.

Traditional	200	190	180	170	160	150	140	130
Current	194	187	180	173	166	159	152	145
Difference	+6	+7	± 0	-3	-6	-9	-12	-15

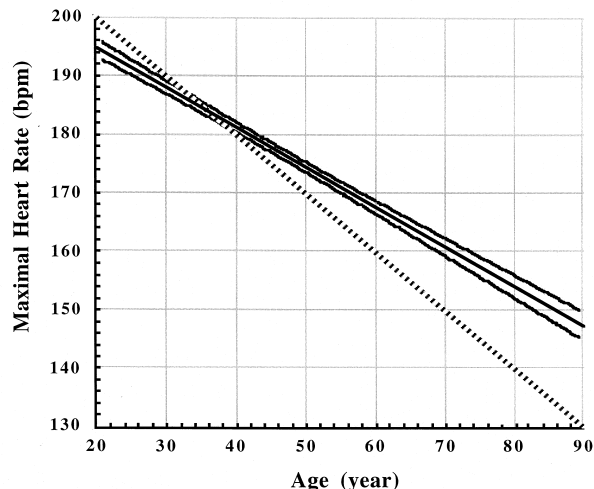


Figure 3. Regression lines depicting the relation between maximal heart rate (HR_{max}) and age obtained from the results derived from our equation ($208 - 0.7 \times \text{age}$) (solid line with 95% confidence interval), as compared with the results derived from the traditional $220 - \text{age}$ equation (dashed line). Maximal heart rates predicted by traditional and current equations, as well as the differences between the two equations, are shown in the table format at the top.

Comparison with the traditional equation. The original reports proposing the $220 - \text{age}$ HR_{max} equation appear to be reviews by Fox and Haskell in the 1970s (7,8). The age-predicted equation was determined “arbitrarily” from a total of 10 studies. The highest age included was < 65 years, with the majority of subjects being ≤ 55 years old. Because of these limitations, there have been some attempts to establish a more appropriate equation to predict HR_{max} (9-11). However, similar to the original reports by Fox and Haskell (7,8), these studies probably or definitely included subjects with cardiovascular disease who smoked and/or were taking cardiac medications. Each of these conditions influences HR_{max} independent of age (10,12,13). Therefore, the present study is the first to determine the age-predicted equation for healthy, unmedicated and nonsmoking adult humans. Another unique aspect of the present study is that each subject achieved a verified maximal level of effort, as established by conventional maximal exercise criteria (e.g., a plateau in $\dot{V}O_2$, maximal respiratory exchange ratio > 1.15).

We obtained the regression equation of $208 - 0.7 \times \text{age}$ to predict HR_{max} in the present study. When this equation was compared with the traditional $220 - \text{age}$ equation (Fig. 3), it is clear that the traditional equation overestimates HR_{max} in young adults, intersects with the present equation at age 40 years and then increasingly underestimates HR_{max} with further increases in age. For example, at age 70 years, the difference between the two equations is ~ 10 beats/min. Considering the wide range of individual subject values around the regression line for HR_{max} ($SD \sim 10$ beats/min), the underestimation of HR_{max} could be > 20 beats/min for some older adults. Although the present HR_{max} equation

provides a more accurate estimation of HR_{max} on average, as with previous equations, it may not precisely predict true HR_{max} in some individuals, because of the standard deviation. As such, despite the convenience and ease of use of age-predicted HR_{max} , direct measurements of HR_{max} should be used as an indicator of physical stress whenever possible. Alternatively, individuals may choose to use more subjective end points of exercise, such as breathlessness and/or a fatigue level considered to be "somewhat hard" to "hard" on the Borg perceived exertion scale (2).

Clinical implications. These differences in HR_{max} could have a number of important clinical implications for older adults. First, because exercise testing is terminated when subjects reach a certain percentage of predicted HR_{max} (e.g., 85% HR_{max}) in some clinical settings (3), use of the prevailing prediction equation would result in premature termination of the test and possibly failure to attain required exertion levels for diagnostic validity. Second, for physical activity intervention programs, an aerobic exercise prescription based on the traditional equation would result in a target heart rate below the intended intensity which may also be optimal for producing health benefits). Third, in fitness and health settings, maximal aerobic capacity is commonly predicted by extrapolating submaximal heart rate to age-predicted HR_{max} (e.g., YMCA cycle protocol) (1). Under these conditions, use of the prevailing equation would result in an underestimation of aerobic fitness levels.

Factors influencing HR_{max} . We found that the rate of decline in maximal heart rate was not associated with either gender or physical activity status. More importantly, a large portion of variability was explained by age alone. These results collectively indicate that the same age-based equation can be used for various groups of healthy adults to estimate their HR_{max} values. We wish to emphasize, however, that because we excluded individuals with overt cardiovascular disease and smokers (10,12,13), the present equation may not be applicable to these subjects.

Mechanisms. The mechanism underlying the age-related reduction in HR_{max} is not clear. It has been postulated that the primary mechanism is related to an age-related decline in intrinsic heart rate (i.e., independent of autonomic influences) (14,15). In this context, it is interesting to note that the rate of decline in HR_{max} observed in the present study is very similar to that reported previously for intrinsic heart rate determined after cardiac autonomic blockade (-0.6 - 0.8 beats/min per year) (14,15). Moreover, consistent with the present findings, gender (14) and habitual physical activity (16) do not appear to influence intrinsic heart rate in humans. These results collectively suggest that a decrease in HR_{max} with age may primarily be due to the reduction in intrinsic heart rate.

Conclusions. The results of the present study fail to validate the traditional equation for predicting HR_{max} across

the adult age range in healthy humans. Specifically, the traditional equation underestimates HR_{max} past age 40 years, markedly so in older adults. On the basis of the cross-confirmatory findings of our meta-analysis and complementary prospective study, we present a new equation for future use that should provide more precise results. These findings have important clinical implications related to exercise testing and prescription.

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