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 – heart rate at rest) is 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.

Because maximal exercise testing is not feasible in many settings, HR_max is often estimated using the age-predicted equation of 220 – 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 – 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
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 subject groups (161 female and 331 male groups) and 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 154 Tanaka et al.

Abbreviations and Acronyms

HR_{max} = maximal heart rate

V\dot{O}_2 = minute oxygen consumption

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

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 age), active
The primary findings of the present study are as follows. First, a regression equation for estimating HR\(_{\text{max}}\) is 208 – 0.7 \times \text{age} in healthy adult humans, which is significantly different from the traditional 220 – \text{age} equation. Second, HR\(_{\text{max}}\) 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\(_{\text{max}}\) 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\(_{\text{max}}\)-derived target heart rate prescriptions.

**DISCUSSION**

Comparison with the traditional equation. The original reports proposing the 220 – \text{age} HR\(_{\text{max}}\) 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\(_{\text{max}}\) (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\(_{\text{max}}\) 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 \(\dot{V}_\text{O}_2\), maximal respiratory exchange ratio \(>1.15\)).
provides a more accurate estimation of $HR_{\text{max}}$ on average, as with previous equations, it may not precisely predict true $HR_{\text{max}}$ in some individuals, because of the standard deviation. As such, despite the convenience and ease of use of age-predicted $HR_{\text{max}}$, direct measurements of $HR_{\text{max}}$ 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 $HR_{\text{max}}$ 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 $HR_{\text{max}}$ (e.g., 85% $HR_{\text{max}}$) 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 $HR_{\text{max}}$ (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 $HR_{\text{max}}$.** 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 $HR_{\text{max}}$ 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 $HR_{\text{max}}$ 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 $HR_{\text{max}}$ observed in the present study is very similar to that reported previously for intrinsic heart rate determined after cardiac autonomic blockade (−0.6 to 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 $HR_{\text{max}}$ 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 $HR_{\text{max}}$ across the adult age range in healthy humans. Specifically, the traditional equation underestimates $HR_{\text{max}}$ 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.

**REFERENCES**


