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How to calculate a maximum heart rate correctly?

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Abstract

Maximum heart rate (HR_{max}) is usually defined as the highest heart rate achieved during maximum physical exertion and depends mainly on age, but also to a lesser extent on other parameters such as: body mass index, body composition, physical capacity, age, gender and the type of exercise test. Measurement of HR_{max} takes place both in cardiology and in sports during exercise testing. In many situations, it is difficult to determine the maximum heart rate during the test and it becomes necessary to estimate HR_{max} based on the knowledge of the above-mentioned factor. This paper also presents the methods of carrying out exercise tests and the influence of pharmacotherapy on the results obtained.

Key words: maximum heart rate, sinus node, physical exertion, electrocardiogram, oxygen intake

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Introduction

Maximum heart rate (HR_{max}) is usually defined as the highest heart rate reached during maximal exertion. HR_{max} is mainly age-dependent [1]. However, individual differences and arrhythmias cannot be ignored. The maximum heart rate is limited by the length of the refractory period of the atrioventricular node and can reach values of approximately 300/min. The earliest documented and reported ventricular rhythm of 480/min in the medical literature was associated with supraventricular tachyarrhythmia, most likely atrial fibrillation conducted by accessory pathways to the ventricles [2].

Under physiological conditions, heart rate is determined by the function of the sinus node, whose discovery by Martin Fleck and Arthur Keith took place in 1906. Since then, a great deal of research has been conducted regarding its structure and physiological processes. Nevertheless, to this day, all the processes involved in this small structure are still unknown [3].

Anatomy and physiology of the sinus node

More recently, the complexity of the structure of the sinus node located near the superior vena cava junction to the right atrium has been described as well as its connections to atrial (muscle) tissue [4]. The sinus node is made up of cells with stimulatory properties, but also of atrial myocytes, adipocytes and fibroblasts [5]. The sinus node is functionally isolated from other atrial cells, except for well-defined connections. Multicentric activation of the sinus node was found as well as transmission of a potential to the atria both directly in the area of the superior vena cava junction and at a distance of up to 41 mm from this area, indicating the complexity of the sinus node structure, which is confirmed by the occurrence of spontaneous P-wave variability in electrocardiographic recordings [4].

The sinus node is innervated both by cholinergic fibres causing cell membrane hyperpolarisation, resulting in a chronotropic negative effect, and by adrenergic postganglionic fibres causing an acceleration of resting

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depolarisation, which has a positive effect on chronotropism [3].

There is evidence of age-related remodelling of the sinus node, but also in the course of other clinical situations, such as heart failure, atrial arrhythmias, asynchronous ventricular pacing or atrial septal defect [6].

Kistler et al. [7] reported differences in terms of the time of sinus node regeneration in persons over 60 years of age compared with those under 30 years of age. As shown in other histological studies, this was not related to fibrosis (collagen fibre content was studied) but to changes in conductance capacity associated with a decrease in the expression of connexin-43 and the number of L-type calcium channels [8]. These changes lead to a progressive decrease in cardiac chronotropic adaptation and, in their exacerbated form, can be the cause of sinus node disease. Also in heart failure and in supraventricular arrhythmias, such as in the course of atrial fibrillation, there is electrical remodelling causing a reduction in the I(f) current and down-regulation of the I(f) current that leads to a gradual decrease in the ability of the sinus node to generate higher heart rates [6]. Moreover, an age-related progressive reduction in the response of sinus node cells to beta-adrenergic stimulation contributes to the decrease in heart rate and ultimately to the decrease in maximum heart rate [4].

Importance of HR_{max}

Exercise tests, and thus the assessment of maximum heart rate, are performed in asymptomatic healthy individuals to detect hidden diseases, minimise the risks associated with exercise, and assess physical performance. HR_{max} value is also needed for setting training loads (determining training zones based on it), monitoring training intensity and its effects [9]. Many training plans are developed based on maximum heart rate. HR_{max} assessment during an exercise test is also performed in patients with cardiovascular and respiratory diseases and as part of the diagnosis of dyspnoea, chest pain, cardiac arrhythmias or syncopes. The reason for determining the maximum heart rate is, among other things, to assess the patient's functional performance, the efficiency of the coronary circulation and thus to diagnose ischaemic heart disease. This study also aims to both assess the blood pressure response to exercise and search for activity-induced cardiac arrhythmias [10].

Methods for determining HR_{max}

Currently, the most accurate way to determine HR_{max} is to perform an exercise test that is usually performed on a treadmill or cycle ergometer. However, determination of HR_{max} requires reaching maximal exertion, which in many cases is difficult and sometimes impossible. This is determined, among other things, by the patient's motivation, musculoskeletal limitations, choice of test method and test protocol [11].

In many exercise testing laboratories, tests are performed based on estimated HR_{max} values.

When load is increased, the increase in heart rate is linear. In the final phase, as in oxygen uptake (VO_2), there is a gradual slowing down of its rate of increase until it reaches a *plateau* in the final phase of the test when maximal exertion is reached [12]. Its maximum value shows significant inter-individual differences of up to 10–15 beats/min. The main factor that affects HR_{max}, as mentioned before, is age [11]. This fact and simplicity of applying the 220 – age of subject in years formula make this the most routinely used formula for calculating HR_{max}. However, it is not only age but also the type of exercise that contribute to achieved heart rate values at peak exercise [13]. Maximal values are reached during physical activities that involve greater muscle mass, such as running or rowing. Slightly lower heart rate values at peak exercise (HR_{peak}) are achieved during cycling. Therefore, different HR_{max} values are reached during tests performed on a cycle ergometer than during treadmill tests [13]. Like in determination of maximal oxygen uptake (VO_{2max}) and VO_{2peak}, HR_{peak} refers to the maximum heart rate reached during physical activities that do not involve a large amount of muscle mass. Therefore, muscle fatigue and discomfort occur sooner during these activities compared to cardiovascular loading. In cyclists, these differences can blur. Even lower HR_{peak} values are achieved during swimming, which is due to a horizontal position and thus increased venous return and increased ventricular filling during the diastolic phase. This results in an increased stroke volume, which makes a greater than the increase in heart rate per cardiac output. In addition, during immersion in water, there is a reflex reaction of the vagus nerve that causes a reduction in heart rate.

Criteria for discontinuation of an exercise test

The exercise test usually lasts until the patient reaches maximal exertion according to the Borg scale [14]. Given the large inter-individual differences, reaching the estimated HR_{max} during the test should not be a reason to terminate the test. The trial is discontinued before maximal exertion is reached if there is a presence of significant (subjective) symptoms, such as dizziness, impaired coordination, severe angina or dyspnoea, pale skin, cyanosis, vegetative symptoms (drenching cold sweats), or a presence of objective reasons, such as dangerous arrhythmias, acute left bundle branch block or a progressive drop in blood pressure [13].

Methods for estimating HR_{max}. Effect of various factors on HR_{max}

In clinical practice, maximum heart rate is the most commonly used parameter for determining maximal exertion, as a result of the wide availability of devices to measure it (pulse oximeters, electrocardiogram). Occasionally, tests such as spiroergometry or lactate testing (blood lactate measurements and analysis during exercise) are performed to assess metabolic parameters more accurately. However, these are less accessible and/or invasive methods. The value of maximum heart rate has significant inter-individual variability. The most commonly used method for determining (estimating) HR_{max}, especially in tests performed on an exercise treadmill, is the 220 – age formula (in tests performed on a cycle ergometer, the 200 – age formula is sometimes used). The use of the above-mentioned formulas is not supported by scientific research and is based on many years of observation. The 220 – age formula first appeared in the medical literature in 1971. The Tanaka's formula (208 – 0.7 × age) [15], Londeree formula (206.3 – 0.711 × age) [16], Inbar formula (205.8 – 0.685 × age) [17] and Nes formula (211 – 0.64 × age) [18] are also frequently used. Based on a recent analysis of spiroergometric tests performed on a large population of physically active individuals [11], the accuracy of the most commonly used formulas for estimating maximum values for exercise heart rate was compared. There were substantial deviations of up to 10–12 beats/minute between estimated values and those actually achieved. All these formulas had similar mean absolute error (MAE). The lowest error was observed in the Tanaka's formula (MAE is approximately 7 beats//minute). The 220 – age method, which is most commonly used formula, is relatively accurate in 30-40 age group but imprecise in both older and younger individuals. Therefore, the widespread use of this formula is not advisable (inaccuracy of results, mismatched load during training planning). Other formulas have similar MAEs of approximately 10 heartbeats/minute.

This study also analysed the effect of various factors on HR_{max} [11]. Parameters such as body mass index (BMI), body composition, physical performance, age, sex, and type of an exercise test were taken into consideration. Multivariate models slightly reduced the degree of error in the estimation of maximum heart rate (HR_{max}). However, given the specificity of the study group and the potential use of this formula in physically active individuals, including elite athletes, these slight differences between the age-only model and the multivariate model may have important implications for training planning and performance in sport disciplines trained. A formula for estimating HR_{max} in physically active individuals was determined [11]:

$$202.5 - 0.53 \times \text{age}$$

and in the multivariate model [11]:

$$229 - 0.64 \times \text{age} - 0.23 \times \text{body mass} + 0.02 \times \text{BMI} - 0.38 \times VO_{2max} + 0.33 \times \text{body fat} + 0.02 \times \text{fitness level} + 8.74 \times \text{sex} + 0.97 \times \text{testing modality}$$

VO_{2max} in mL × kg^{-1} × min^{-1}, age in years, body weight in kg, sex: 1 male, 0 female; test type: 1 treadmill, 0 cycle ergometer

The formulas in question had the smallest error among the aforementioned methods for estimating HR_{max} (MAE 7.04) [11]. However, the characteristics of the study group should be noted. The study group consisted of mostly young, physically active individuals. For such a group, the use of the developed formulas could contribute to improved training planning, better training monitoring and evaluation of effects. However, it should not be overlooked that a direct measurement of HR_{max}, as opposed to an estimation of HR_{max}, will not be burdened with an error and determination of this measurement should be ensured in a person tested.

Effect of medications on HR_{max}

When assessing the heart rate during an exercise test, it is necessary to take into account medications that a tested person is taking. Beta blockers and ivabradine reduce both resting heart rate and HR_{max} by approximately 10–15 beats/minute. Digitalis glycosides and negative chronotropic calcium channel antagonists primarily affect resting heart rate values. Ivabradine lowers both resting and exercise heart rates by approximately 10–15 beats/min without significantly altering heart rate reserve [19].

Conclusions

Maximum heart rate is used in both cardiology and sports medicine as a criterion for achieving maximal exertion. HRmax is usually determined during tests in exercise testing laboratories. Usually, the test is discontinued before maximal exertion is reached. In such situations, HR_{max} estimation methods enable an assessment of functional performance (HR achieved as a percentage of HR_{max} during a trial terminated prematurely) and the development of appropriate training. Previous formulas for determining HR_{max} were based mainly on age. The most commonly used 220 – age method is still one of the basic methods. Recently, however, this method has been increasingly replaced by the more accurate Tanaka's formula (208 – 0.7 × age). The HR Max Prediction Based on Age, Body Composition, Fitness Level, Testing Modality and Sex in Physically Active Population study analysed the effects of other factors on HR_{max} in physically active individuals. In such individuals, the application of the 202.5 – 0.53 × age formula has a slightly smaller (mean) absolute error. The multivariate method, which takes into account other parameters such as BMI, body composition, degree of training or type of test, enables slightly greater accuracy in estimating HRmax, which may be important in the case of elite athletes. However, the basis for determining HR_{max} remains direct measurement during maximal exertion, as this is the only way to obtain an error-free result. Therefore, in the absence of objective indications to discontinue the test, it should be continued until maximal exertion is achieved.

Conflict of interest

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