The Effect of Age on Heart Rate in Subjects Free of Heart Disease

Studies By Ambulatory Electrocardiography and Maximal Exercise Stress Test

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SUMMARY To delineate the effects of true aging, undetected heart disease and deconditioning on heart rate, we performed 24-hour ambulatory electrocardiography and maximal exercise stress test on 101 subjects with normal hearts. The maximal heart rate recorded was 180 beats/min; the minimum was 35 beats/min. A distinct diurnal pattern was observed.

With increasing age, a decrease of the maximal heart rate achieved during exercise stress test \( r = 0.27, p = 0.05 \) or spontaneously recorded during the day \( r = 0.41, p = 0.0005 \) or night \( r = 0.24, p = 0.03 \) was observed. The resting and average heart rates were not affected by age. Older subjects had lower exercise tolerance \( r = 0.41, \ p = 0.0001 \). Low exercise tolerance was associated with higher increments of heart rate for submaximal exercise levels \( r = 0.53, p = 0.001 \), steeper increase of heart rate with increasing intensity of exercise \( r = 0.68, p = 0.0001 \) and lower maximal heart rates \( r = 0.43, p = 0.008 \).

These changes of heart rate with age are not due to undetected cardiac disease, because the subjects included in the study were meticulously screened by noninvasive and invasive means.

MANY STUDIES have shown that the maximal exercise heart rate declines with age.1-4 The intrinsic heart rate after autonomic blockade with atropine and propranolol also decreases with age with a slope similar to that of the maximal exercise heart rate.5 However, the average daily heart rate is not influenced by age,6,7 and contradictory or few data are available on the effect of age on resting heart rate, on the increment of heart rate induced by standardized exercise and on the diurnal variation of heart rate.1,3-8,10-18

A common problem in studying the effect of age on the heart is the difficulty in separating the true effects of aging from those due to deconditioning or unrecognized diseases. Deconditioning due to sedentary lifestyle is a common accompaniment of aging, and undetected significant coronary artery disease may be present in more than one-fourth of persons older than 45 years of age.18-22

In the studies mentioned above, the effect of age cannot be clearly distinguished from the effects of subclinical coronary artery disease or deconditioning. To further define the effect of age on the heart rate, we performed 24-hour ambulatory electrocardiography and maximal exercise stress testing on 101 subjects free of detectable heart disease verified by extensive noninvasive and invasive testing.

Materials and Methods

Population

One hundred one subjects with normal hearts were identified among 1500 patients referred for cardiac catheterization to the laboratories associated with CMDNJ-Rutgers Medical School for the differential diagnosis of chest pain. These subjects had normal physical examination of the cardiovascular system and normal chest x-ray, ECG, echocardiogram, maximal exercise stress test using a Balke protocol,23 right- and left-heart catheterization and coronary arteriography. Patients with coronary artery disease compromising the lumen of a major branch by even 5%, impaired left ventricular function manifested by an ejection fraction smaller than 0.5, or left ventricular end-diastolic pressure higher than 12 mm Hg were excluded. Patients with mitral valve prolapse, cardiomyopathy, asymmetric septal hypertrophy, valvular disease, pulmonary hypertension or an abnormal stress test (more than 0.075 mV of horizontal or downsloping ST depression) were also excluded from the study. Subjects with low exercise tolerance but without other abnormalities during stress test were allowed to participate. Patients with significant extracardiac disease diagnosed by physical examination, chest x-ray, complete blood count, urinalysis and biochemical screen (blood sugar, BUN, creatinine, bilirubin, total protein, albumin, uric acid, alkaline phosphatase, SGOT, LDH, cholesterol, triglycerides, serum calcium, sodium, potassium, chloride and carbon dioxide) were excluded. The sex, weight, height and body mass index (an index of obesity derived by dividing the weight by the square of the height) of each subject and the use of tobacco, alcohol, coffee and tea were noted.

There were 50 women and 51 men, average age 48.8 years (range 16–68 years). A cause for the chest pain that prompted the coronary arteriography was found retrospectively in 51 subjects: Esophageal disorder was identified in 29, cervical osteoarthritis in 19, chest wall tenderness in 13 and psychological abnormalities were thought to account for the pain in seven sub-
Ambulatory Electrocardiography

Twenty-four-hour ambulatory electrocardiography was performed using portable two-channel tape recorders to obtain two leads corresponding to modified V_1 and V_6 (Avionics Model #445). The tapes were played back on a 660A Avionics playback system by an experienced nurse. The heart rate was measured on an analog recording of the heart rate vs time obtained from the playback system (trend recording) and verified by obtaining ECGs at 25 mm/sec.

The following variables were measured and entered into an IBM 370/168 computer for statistical analysis using an SAS program: age, sex, weight, body mass index, serum calcium, sodium, potassium, hemoglobin, systolic blood pressure, diastolic blood pressure, number of cigarettes smoked per day, number of ounces of alcohol consumed per week, number of cups of caffeinated coffee and tea per day. The following variables (developed for this study) affecting the heart rate were also entered: the maximal, minimal and average heart rates in each hour, the difference between maximal and minimal heart rate in each hour, the average maximal heart rate (the sum of the maximal heart rates in each of the 24 hours divided by 24), the average minimal heart rate (the sum of the minimal heart rates in each of the 24 hours divided by 24), the average average (overall average) heart rate (the sum of the average heart rates in each of the 24 hours divided by 24), and the maximal and minimal heart rates recorded. The same variables were obtained for daytime hours (9 a.m. to 1 p.m.) and for nighttime hours (1 a.m. to 5 a.m.) when all subjects were asleep. All subjects were awake and engaged in their usual activities between 9 a.m. and 1 p.m. The subjects had sedentary occupations and did not exercise routinely.

The following variables were obtained from the exercise stress test: exercise tolerance (the exercise performed at the end of maximal exercise test in metabolic equivalents), maximal heart rate achieved during exercise stress test, the heart rate at each exercise level, and the rate of change of heart rate with increasing intensity of exercise (obtained by dividing the heart rate increment induced by maximal exercise by the intensity [duration] of maximal exercise).

The recovery of heart rate after exercise was calculated in three ways: the decrement of heart rate from the maximum achieved during exercise within 2 and 4 minutes after exercise, the number of beats by which the heart rate 2 and 4 minutes after exercise exceeded the resting heart rate, and the percent recovery of the heart rate obtained by dividing the decrement of heart rate at a given time (2 and 4 minutes) after exercise by the total exercise-induced increment in heart rate in each subject.

Statistical analysis was performed for 97 subjects who had satisfactory recordings of ambulatory electrocardiography and exercise stress test by constructing a correlation matrix of the relationship of each variable mentioned above to all others, and when appropriate, by cross tabulations and by chi-square and t tests.

Results

The results are presented in tables 1 and 2 and figures 1-3.

Diurnal Variation of Heart Rate

The diurnal variation of heart rate is shown in figure 1. Maximal heart rates occurred in the late morning and minimal rates occurred between 3 and 5 a.m. Heart rate varied widely within each hour of the day and night. The minimal, average, maximal and the difference between minimal and maximal heart rates were lower at night (t = 6.41-9.69, p < 0.0001; table 1). The maximal heart rate recorded was 180 beats/min and the minimum was 35 beats/min.

Ambulatory Electrocardiography

A significant negative correlation of age with exercise tolerance (r = 0.41, p = 0.001) was observed. Age was also associated with height (r = -0.22, p = 0.045) and systolic blood pressure (r = 0.28, p = 0.01). With increasing age, the average maximal heart rate during day and night declined significantly. The maximal heart rate and the difference between maximal and minimal heart rates declined significantly during the day (table 2, fig. 2).

Table 1. Heart Rates in Normal Subjects

<table>
<thead>
<tr>
<th></th>
<th>24 Hours</th>
<th></th>
<th></th>
<th></th>
<th>Night</th>
<th></th>
<th></th>
<th>Difference between day and night</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Avg max HR</td>
<td>99.3</td>
<td>10.3</td>
<td>106.5</td>
<td>14.2</td>
<td>88.9</td>
<td>12.7</td>
<td>17.3</td>
<td>15.0</td>
</tr>
<tr>
<td>Avg min HR</td>
<td>71.2</td>
<td>8.5</td>
<td>74.9</td>
<td>9.8</td>
<td>66.3</td>
<td>10.7</td>
<td>8.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Overall avg HR</td>
<td>78.9</td>
<td>8.8</td>
<td>84.2</td>
<td>11.5</td>
<td>70.0</td>
<td>10.0</td>
<td>13.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Max observed HR</td>
<td>127.2</td>
<td>17.4</td>
<td>115.9</td>
<td>16.7</td>
<td>96.5</td>
<td>16.5</td>
<td>19.3</td>
<td>18.2</td>
</tr>
<tr>
<td>Min observed HR</td>
<td>58.8</td>
<td>9.6</td>
<td>69.6</td>
<td>10.3</td>
<td>62.4</td>
<td>10.8</td>
<td>7.2</td>
<td>10.0</td>
</tr>
<tr>
<td>Avg dif between max and min HR</td>
<td>28.1</td>
<td>7.2</td>
<td>31.3</td>
<td>10.7</td>
<td>22.6</td>
<td>8.2</td>
<td>8.4</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Abbreviation: HR = heart rate (beats/min).
TABLE 2. Effect of Age on Heart Rates

<table>
<thead>
<tr>
<th></th>
<th>24 Hours</th>
<th>Day</th>
<th>Night</th>
<th>Difference between day and night</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td></td>
<td>r</td>
</tr>
<tr>
<td>Avg max HR</td>
<td>-0.41</td>
<td>0.0005</td>
<td>-0.29</td>
<td>0.01</td>
</tr>
<tr>
<td>Avg min HR</td>
<td>-0.18</td>
<td>NS</td>
<td>-0.16</td>
<td>NS</td>
</tr>
<tr>
<td>Overall avg HR</td>
<td>-0.12</td>
<td>NS</td>
<td>-0.03</td>
<td>NS</td>
</tr>
<tr>
<td>Max observed HR</td>
<td>-0.31</td>
<td>0.004</td>
<td>-0.31</td>
<td>0.0005</td>
</tr>
<tr>
<td>Min observed HR</td>
<td>-0.10</td>
<td>NS</td>
<td>-0.18</td>
<td>NS</td>
</tr>
<tr>
<td>Avg dif between max and min HR</td>
<td>-0.38</td>
<td>0.002</td>
<td>-0.24</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Abbreviation: HR = heart rate.

Significant effects of age on minimal and average heart rates and on the difference in heart rates between day and night were not observed. Subjects with high exercise tolerance tended to have a lower minimal heart rate during the day and night ($r = 0.28, p < 0.05$) and a higher maximal heart rate during the exercise stress test ($r = 0.43, p < 0.008$). However, the average maximal heart rate recorded by ambulatory

FIGURE 1. Diurnal variation of heart rate. MxHR = maximal heart rate in hour; MnHR = minimal heart rate; AveHR = average heart rate. The 95% confidence limits are shown. The average heart rate tends to remain closer to the minimal heart rate than to the maximal heart rate.

FIGURE 2. Effect of age on heart rate during the day. MAXIMUM = average maximal heart rate; MINIMUM = minimal heart rate; AVERAGE = average heart rate; DIFFERENCE = difference between maximal and minimal heart rates.
Figure 3. Effects of exercise tolerance (EXERCISE PHASE = exercise at the end of maximum exercise test) on heart rate during exercise. MAXIMUM INCREMENT = increment of heart rate induced by maximal exercise; SUBMAXIMUM INCREMENT = increment of heart rate induced by standardized (6 mets) submaximal exercise; RATE OF CHANGE = rate of change of heart rate with increasing exercise level computed by dividing the increment of heart rate induced by maximal exercise by the intensity of maximal exercise (exercise phase). Subjects with high exercise tolerance achieve higher maximal heart rate but have lower submaximal rates for any given exercise intensity.

Electrocardiography was not affected by exercise tolerance ($r = 0.03$, NS).

There were strong positive correlations between the average maximal heart rate and the average minimal heart rate ($r = 0.73$, $p = 0.0001$), the average heart rate ($r = 0.67$, $p = 0.0001$), the difference between the average maximal and minimal heart rates ($r = 0.57$, $p = 0.0001$), and the difference between maximal heart rate during the day and night ($r = 0.22$, $p = 0.064$). Obesity (body mass index), male or female sex, smoking, and the biochemical variables had no significant effects. The use of alcohol was associated with higher minimal ($r = 0.36$, $p = 0.005$) and average ($r = 0.26$, $p = 0.03$) heart rates.

Maximal Exercise Treadmill Test

During the maximal exercise test, older subjects achieved lower maximal exercise heart rates ($r = 0.27$, $p = 0.05$), had lower exercise tolerance ($r = 0.41$, $p = 0.01$) and showed a steeper increase in heart rate with exercise ($r = 0.30$, $p = 0.05$). Increasing age resulted in a slower decline of heart rate after exercise (at 2 minutes $r = 0.28$, $p = 0.05$). No change in the recovery expressed as a percentage of the exercise-induced increment in heart rate was noted.

Subjects with high exercise tolerance achieved higher maximal heart rates ($r = 0.42$, $p = 0.008$), had lower submaximal heart rates ($r = 0.52$, $p = 0.001$ for phase 1; $r = 0.55$, $p = 0.0007$ for phase 2; $r = 0.72$, $p = 0.0001$ for phase 3; $r = 0.65$, $p = 0.0006$ for phase 4; $r = 0.76$, $p = 0.0002$ for phase 5 of the exercise protocol) and had a smaller rate of change of heart rate with exercise ($r = -0.68$, $p = 0.0001$) (fig. 3). Subjects with high exercise tolerance also showed a faster decline of heart rate at a given time after exercise ($r = 0.44$, $p = 0.007$ at 2 minutes; $r = 0.48$, $p = 0.003$ at 4 minutes). However, these subjects had a higher heart rate at a given time after recovery than subjects with low exercise tolerance ($r = 0.30$, $p = 0.007$ at 2 minutes; $r = 0.35$, $p = 0.04$ at 4 minutes). Therefore, a consistent effect of exercise tolerance on the percentage of the exercise-induced rate increment that recovered at a given time after exercise was not observed. The presence or absence of esophageal disorder, cervical osteoarthritis, chest wall tenderness or psychological abnormality as the cause of pain that led to the catheterization did not affect the resting or exercise heart rates.

Discussion

The decrease in maximal exercise heart rate with increasing age in this population is in agreement with previous studies. In addition, ambulatory electrocardiography revealed an age-related decrease in spontaneously achieved maximal heart rate. This decrease was not solely due to avoidance of strenuous activity by older persons, for it occurred during the day and at night, when all subjects were asleep. The fact that age did not affect the difference in heart rate between day and night also implies that variations in activity were not the only reason for the decline of maximal heart rate with age. Another cause may be a decline in the capacity of the sinus node to increase the heart rate. Aging is associated with changes in pacemaker tissue, a decrease in the responsiveness of autonomic cardiovascular reflexes, a decline in the intrinsic heart rate, and decreased adrenergic receptor sensitivity. Decreased responsiveness of the sinus node to catecholamines may also explain the lower nighttime maximal heart rate of older subjects despite increased plasma norepinephrine levels at night and higher levels of wakefulness and insomnia.

The apparent contradiction between the decline of maximal heart rate with age and the absence of an effect of age on the average heart rate may be reconciled by considering the effect of age on the heart-rate response to exercise. In our study, the rate of change of heart rate with increasing exercise level increased with age. Although older subjects have a lower intrinsic heart rate, the increment of heart rate caused by daily activities may be higher, resulting in an average
heart rate similar to that of younger subjects. In addition, sympathetic activity measured by plasma norepinephrine levels during the day and night, at rest and in response to postural changes or to static exercise are higher in older subjects.  

The delayed recovery of heart rate after exercise in older subjects has been reported.  

It could be because for a given exercise level, older subjects use more of their reserve and depend more upon anaerobic metabolism than younger subjects. Bruce et al. reported a decline in the chronotropic capacity with age, which resulted in use of greater chronotropic reserve and delayed heart rate recovery after exercise. The decreased exercise tolerance of older subjects may also explain the decrease in heart rate recovery after exercise, because conditioned subjects show a larger heart rate decrement at a given time after exercise.  

Although cardiac disease was excluded by meticulous screening, the patients in this study were referred to us for chest pain and do not represent a random sample of normal subjects. Therefore, inferences on intrinsic heart rate from other studies may not necessarily apply to this population. However, the fact that similar results were obtained in the presence or absence of each cause of chest pain implies that the data reported here pertain to normal subjects.

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