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Characteristics of basal heart rate during daily life: Influences of age, gender, and seasons

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Abstract

With widespread use of wearable sensors, vast data of heart rate (HR) during daily activities are accumulated. HR, however, is known to change with body posture and activities and show age and sex dependency and circadian variations. To interpret and effectively utilize the HR data, an individual reference value of HR is necessary. Using 24-h HR big data in 253,673 subjects under daily activities, we investigated the characteristics of basal HR, the lowest HR in the day, as a promising candidates for the reference point. We found that although basal HR decreases with age until 20 yr old, it shows no significant age-dependent change thereafter. Basal HR showed seasonal variations, increasing during cold season and decreasing during hot season. The clock time to reach basal HR appeared between 02 and 05 h on average and showed slight progress or delay depending on the time of life.

1. Introduction

Increase in heart rate (HR) is widely used as an index of physical and mental stress in laboratory studies. Recently, with widespread use of wearable sensors, vast HR data during daily activities are accumulated[1,2] and interpretations of HR data are required for their effective utilization. For HR during ambulatory monitoring, however, the reference value of HR is lacking; consequently, the HR data of individual subject cannot be assessed appropriately. HR, even during resting, is known to change with body posture, differ with age, and show circadian

variations. To interpret the meaning of HR data, it is necessary to set the value as the reference point for each individual. Although resting HR has been used for this purpose, the definition of resting HR has not been established and particularly, the effects of time of the day(circadian rhythm) on resting HR have not been considered. One of the most promising candidates for the reference point is basal HR, i.e., the lowest HR in the day.In the present study, we investigated the characteristics of basal HR using big data of 24-h ambulatory electrocardiographic (ECG) recordings that have been collected by the Allostatic State Mapping by Ambulatory ECG Repository (ALLSTAR) project 3-5.

2. Methods

The protocol of this study has been approved by the Ethics Review Committee of Nagoya City UniversityGraduate School of Medical Sciences (No. 709).

2.1. Database

We used a database of 24-h ECG of the ALLSTARproject {Yuda, 2016 #9069;Yuda, 2017 #9068;Hayano,2018 #9195}. The project has been started in 2010. The24-h ECG data were recorded for clinical purposes and referred for analysis to three ECG analysis centres(SUZUKEN Co., Ltd., Japan) located in Tokyo, Nagoya, and Sapporo in Japan. To utilise the data for the ALLSTAR research project, the data were anonymized and stored with subjects' age, sex, and recoding date, time, and location (postal code).

According to the Ethical Guidelines for Medical and health Research Involving Human Subjects (by the Ministry of Education, Culture, Sports, Science and technology and the Ministry of Health, Labour andWelfare, Japan, December 22, 2014), the purpose utilized in this research have been public through the homepages of Suzuken Co., Ltd. (http://www.suzuken.co.jp/product/holter/detail/) and also of the ALLSTAR research project (http://www.med.nagoya-cu.ac.jp/mededu.dir/allstar/), in which opportunities to refuse the uses of information are ensured for the research subjects.

The Holter ECG recorders that have been used for these data collections were Cardy 2, Cardy 2P, Cardy 203,Cardy 301, Cardy 302 Mini and Max, Cardy 303 pico andCardy 303 pico+ (SUZUKEN Co., Ltd., Nagoya, Japan),by which 24-h multi-channel ECG data were digitized at125 Hz and stored in memory. The digitized ECG data were sent to one of the three ECG analysis centres, where the data were analysed with Holter ECG analysers (CardyAnalyser 05, Suzuken Co., Ltd., Nagoya, Japan) by skilled medical technologists; the temporal positions of all R-waves were detected, the rhythm annotations were given to all QRS complexes, and all errors in automated analysis were corrected manually by the technologists.The suspicious outcomes of the analysis (approximately40% of data) have been reviewed by contracted radiologists.

The ECG data of this study were those obtained from253,673 subjects (median [5-95 percentiles] age, 68 [24-86] yr) including 113,341 males (67 [21-85] yr) and140,332 females (69

[27-87] yr) in whom basic cardiac rhythm was sinus rhythm (defined as >80% of all recorded beats are in sinus rhythm). Figure 1 shows data distribution by 5-yr bin of age in male and female patients. For both genders, the data distributed to all ages, while they were concentrated between 60 to 85 yr old. The data were collected from all over Japan. Figure 2 shows the geographic distribution of data.

Figure 1. Age distributions of the study subjects in the ALLSTAR database

Figure 2. Geographic distributions of ALLSTAR data used in this study

2.2. Measurements

Basal HR was defined as the minimum median value of sinus-rhythm HR within 3-min window during the day. We first calculated the median value of sinus interbeat intervals within moving 3-min window over the entire 24h. Then, we took the max median interval and calculated basal HR as 60,000/(the max median interval, ms) bpm. We also measured the clock time when basal HR was detected in each subject. Also, we calculated 24-h median HR only using interbeat intervals with sinus rhythm and calculated the difference between the median and basal HR.

To investigate the effect of temperature on variation of basal HR, the average temperature of the day at the place of each ECG was recorded. For this purpose, we identified the weather station that was nearest to the recording place according to the postal code accompanying each ECG recording.

2.3. Statistical analysis

Statistical analysis was performed with Statistical Analyses System version 9.4 (SAS institute Inc., Cary, NC, USA). To evaluate the effects of age, the subjects were grouped by age for every 5 years. To evaluate the seasonal variations, the effects of month on variables were analysed. The general linear model was used to evaluate the effects of age, sex, and season on basal HR and clock time at which basal HR appeared. $P < 0.01$ was considered to be statistically significant.

Figure 3. Effects of age and sex on the median (A)and basal (B) heart rate (HR) and their difference (C)Error bars denote SD.

3. Results

3.1. Effects age and sex on basal HR

Figure 3 shows the effects of age and sex on the median and basal HR and difference between them. In both sexes, the median HR was highest for the age bin of 0-4 yr(Figure 3A). It

decreased until 20 yr. Thereafter, it decreased gradually with age (-1.9 bpm/yr for males and -0.14 bpm/yr for females).

The basal HR was also highest for the age bin of 0-4 yr(85 ± 22 bpm for males and 85 ± 23 bpm for females) in both sexes (Figure 3B). It also declined until 20 yr and reached to 48 ± 7 and 51 ± 8 bpm for males and females, respectively. Thereafter, however, it showed no significant change in either sex. Consequently, the difference between median and basal HR decreased with age (-1.7 bpm/yr for males and -0.14 bpm/yr for females), probably reflecting decreasing daily activities with advancing age. On average over the entire age, the basal HR was slightly (only 0.4 bpm) but significantly lower in male than in female (P <0.0001).

Figure 4. Seasonal variation of median HR (A) andbasal HR (B) and difference between them (C) To visualize the cyclic changes, the same datawere displayed for 2 years. Grey line in panel B isaverage temperature of the places at which ECGswere recorded. Data are least-square means andstandard errors of the means adjusted for the effectof age.

Figure 5. Effects of age and sex on the time of basal HR appears (A) and its seasonal variations (B)In panel A, data are mean and SD. In panel B, data are least-square means and standard errors of the means adjusted for the effect of age. To visualize the cyclic changes, the same data weredisplayed for 2 years in panel B.

As shown in Figure 4C, the seasonal variations inthe difference between the median and basal HR wasslight but significant (P <0.0001), indicating that althoughthe changes in the median HR are almost parallel withthose in the basal HR, these is a significant phase delay inthe changes in basal HR against those in the median HR.

3.2. Seasonal variations in basal HR

Figure 4 shows the seasonal variations in the median andbasal HR and in the difference between them. Bothmedian and basal HR showed seasonal variations withincreasing during cold season and decreasing during hotseason (Figure 4A and 4B). In both sexes, the amplitudeof seasonal variation was only about 2 bpm for bothmedian and basal HR and fluctuations appeared asantiphase with those of average temperature observed atthe places of ECG recordings.

3.3. Time of the basal HR

Figure 5 shows the time at which the basal HR appeared.Although the averages of clock times of basal HR wereobserve between 02 and 05 h, the distribution was widefor 0-4 yr old and for over 80 yr old (Figure 5A).Theaverage clock time moved from 02 to 04 h during growthbetween 5 to 20 yr old, moved back to 03 h until 70 yr old,and again moved toward 05 h thereafter. Least squaremeans (SE) of the time of basal HR was 03:45 (1 min)and 03:57 (1 min) for male and

females and 12 min earlierin males (P <0.0001). The time of basal HR showed onlyslight seasonal variations in males and no significantseasonal variation in females (Figure 5B).

4. Discussions

In this study, we investigated the characteristics of basalHR by the analysis of 24-h heartbeat big data of theALLSTAR project. Our major findings are as follows:

(i) The basal HR is highest at 0-4 yr of age. It declineswith age and reaches a plateau at 20 yr old.Thereafter, it keeps a constant level till the end of life.
(ii) The median HR of the day was also highest at 0-4 yrold and declined until 20 yr, but it continued todecrease gradually till the end of life.
(iii) The basal HR is slightly (only 0.4 bpm) butsignificantly lower in male than in female.
(iv) There is a significant seasonal variation in the basalHR. It increased during cold season and decreasedduring hot season.
(v) The average time at which the basal HR occursdistributes between 02 h and 05 h, although itshowed wide distributions in under-4-yr and over-80-yr old subjects.
(vi) The time of the basal HR basal HR occurs slightly(only 12 min) earlier in males than females.
(vii) There is no significant seasonal variation in the timeof basal HR.

With the widespread adoption of wearable sensors, HR is becoming the most universal biosignal available during daily activities.1,2 HR, however, sensitively responds to physical, psychological, and environmental stimuli, fluctuates with intrinsic circadian and ultradian rhythms, changes with aging, and shows the substantial inter-individual difference. To properly interpret personal HRdata in everyday life, individual reference values are necessary. The results of the present study show that the basal HR is one the most promising candidate as an individual's reference HR.

To our knowledge, this is the first study to report the feature of basal HR using ECG big data. Because the ALLSTAR database covered the entire age range (0 to over 100 yr old) for both sexes, we were able to delineate the age dependent changes in the basal HR for each sex.Also, the large sample size of the database gave this study a strong statistical power, which allowed us to delineate the seasonal variations in the basal HR. In an earlier study in 120 healthy men in whom 24 h ECG was recorded in both summer and winter, Kristal-Boneh et al6 examined seasonal differences in 24-h mean heartbeat interval. They failed to detect significant seasonal difference in 24-h mean heartbeat, while they observed increases in HR variability indices reflecting parasympathetic function in summer. In a study of 13 sedentary and 13 physically active workers, Markov et al7 also examined seasonal variations in resting HR. Their data showed slightly greater resting HR in winter (78.5 bpm) than in summer(77.0 bpm) in physically active workers, although the difference did not reach statistical significance. The resting HR in sedentary workers did not differ with season (77.0 bpm for both). In the present study, we observed seasonal variations in the 24-h median HR and basal HR in both sexes, but the

maximum differences (the highest minus lowest months) in age-adjusted least square means were < 2 bpm in either median or basal HR in either sex.The strong statistical power of this study seems to be necessary for detecting such small differences.

We observed that the basal HR shows no significant age-dependency above 20 yr old and no substantial gender difference (on average, only 0.4 bpm higher in females than in males). Also, the time at which basal HR appears distributed around 04 h with only 12-min gender difference on average. These suggest that the basal HRmay be the robust physiological feature of individual subject and thus, it may be used as the reference point ofHR in each subject.

The limitation of this study is that each datum in ALLSTAR database has been collected for a certain clinical purpose. In this sense, the ALLSTAR database may represent characteristics of patients undergoingHolter ECG monitoring examination in Japan. Although we selected only subjects in whom basic cardiac rhythm was sinus rhythm (defined as >80% of all recorded beats are in sinus rhythm), we need to assume that the data are affected by the underlying diseases and by possible differences in the prevalence of those diseases with age and sex. Nevertheless, we observed the stable features of basal HR in the ALLSTAR database. This suggests that the basal HR may be also robust at least to the diseases whose prevalence shows age or sex dependent difference.

5. Conclusions

We investigated the characteristics of basal HR in theALLSTAR 24-h heartbeat big data. We observed that the basal HR above 20 yr old is stable against age, only slightly (0.4 bpm) higher in females than in males, and slightly (< 2 bpm) higher in cold than in hot season. The clock time to reach basal HR appears around 04 h and slightly earlier (12 min) in males. These stable features suggest that the basal HR may be used as the reference point of HR in individual subject.

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