The First Heart Sound Immediately after Exercise as an Index of Exercise Stress

Takuro Matsuda*, Hideaki Kumahara*, Shigeru Obara**, Akira Kiyonaga*, Munehiro Shindo* and Hiroaki Tanaka*

*Fukuoka University, Faculty of Sports and Health Science
8-19-1 Nanakuma Jonan-ku, Fukuoka, Fukuoka 814-0180 Japan
takumatsu81@gmail.com

**The University of Tokushima, Faculty of Integrated Arts and Sciences
1-1 Minamijosanjima, Tokushima, Tokushima 770-8502 Japan

[Received March 13, 2008; Accepted August 20, 2008; Published online May 10, 2009]

INTRODUCTION. This study investigated whether the amplitude of the first heart sound (AHS-1) and the diastolic time (DT) recorded immediately after exercising could be related to those values during exercise.

METHODS. Nine male volunteers (24.6±2.9 years old) participated in this study. A discontinuous graded exercise test was performed on an electrically braked cycle ergometer. The external phonocardiograms were recorded during the test. The 10 highest AHS-1 during the last 30 sec at each stages and 10 consecutive AHS-1 immediately after each stage of exertion were measured. The DT was calculated as the systolic time subtracted from the cardiac cycle time interval assessed by the waveform of the heart sounds in the same time range as the above analysis.

RESULTS. The change of AHS-1 during exercise and immediately after exercise at each stage demonstrated a significant correlation ($r=0.979$, $p<0.01$). The workloads at the breaking point during and immediately after exercise were the same. There were significant correlations between the DT during exercise and immediately after exercise in all ($r=0.951$ to 0.993, $p<0.01$).

CONCLUSION. The results of this study clarified that AHS-1 and DT during exercise can be estimated from the phonocardiogram that is recorded immediately after exercise.

Keywords: phonocardiogram, amplitude of the first heart sound, diastolic time, graded exercise test

[International Journal of Sport and Health Science Vol.6, 213-218, 2008]
clothing, or noises from the surroundings may be easily mixed in. It is also difficult to avoid noises produced in walking or running, particularly on a treadmill. Thus analysis of the heart sounds is impossible, unless a method of recording heart sounds with minimized noises is devised.

HR immediately after exercise has been used for determining exercise intensity. If heart sounds are recorded in a static state immediately after exercise, then the effects of noise can be minimized and the heart sounds can be recorded more clearly. In the same way as the HR reflects the exercise intensity during exercising, if useful information is obtained by heart sounds recorded immediately after exercise, a significantly easy method can be derived for determining safe exercise intensity in exercise prescription for health promotion.

Therefore, our purpose in this study is to clarify the relationship for AHS-1 or DT values obtained during and immediately after exercise.

2. Method

2.1. Subjects

The subjects were 9 young and healthy males. Table 1 summarizes their physical characteristics.

The protocol for this study was approved by the Ethics Committee of Fukuoka University. The subjects understood the objectives and possible dangers, and were enrolled upon signing an informed consent form.

2.2. Exercise test

The submaximal intermittent multistage incremental exercise test was done using a cycle ergometer (Rehcor, Lode Co., The Netherlands). After sitting still for 1 min, the initial load was set as 15 watts and the exercise load was incremented in 15-watt steps. The exercise period was 2 min for each load and this was followed by a 1-min rest. The criterion for terminating the exercise was when HR reached 85% of the maximum HR, which was estimated based on the subject’s age (for a 20 year-old, 220/age = 170 beats). The rate of pedal revolutions of the exercise was set at 50 revolutions per minute.

The microphone for recording heart sounds was an acceleration-type heart-sound microphone (MA-250, Fukuda Denshi Co., Japan), placed 5 cm from the center of the sternum on the left sternal border, at the second intercostal space. All subjects removed their upper clothing in order to prevent producing any noises due to friction between the microphone and the clothing during testing.

During the exercise test, each subject’s electrocardiogram (CARDIMAX FX-3301, Fukuda Denshi Co., Japan) and phonocardiogram (heart sounds/pulse wave unit PL-33, Fukuda Denshi Co., Japan) were continuously recorded. Also, immediately after the completion of each workload, the electrocardiogram and phonocardiogram were recorded for 5-10 sec while the subject held his breath. Outputs of both the electrocardiogram and phonocardiogram were sent to a personal computer using waveform processing software (Chart 5, AD Instruments Co., Australia) via an AD conversion board (PowerLab 8sp, AD Instruments Co., Australia). The sampling rate was set at 1 kHz. BP was measured using an automated BP and HR monitor (CM-4003, Kyokko Bussan Co., Japan).

2.3. Data analysis

The analysis of heart sounds recorded during exercise was performed according to the method by Obara et al. (2005). In short, 10 highest AHS-1 values were selected from among the wave patterns, which were recorded for 30 sec before each workload ended, and the mean values were calculated. Figure 1 shows the analysis of heart sounds recorded during and immediately after exercise. The mean value was calculated from the 10 consecutive cardiac cycles.

AHS-1 and the appearance time of S1 and S2 were measured using waveform processing software (Chart 5, AD Instruments Co., Australia). The AHS-1 was expressed by the ratio of amplitude during or immediately after exercise against that at rest. For determining the HSBP of each subject, AHS-1 of each stage was plotted on a graph against workload. The point of the abrupt increase in AHS-1 against the workload was determined based on a visual inspection,

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>24.6±2.9</td>
<td>171.0±5.8</td>
<td>69.4±13.1</td>
<td>23.6±3.7</td>
</tr>
</tbody>
</table>

The values were shown as the mean±standard deviation.

and the average was determined according to the estimations of three of the experimenters. DT was determined using the following formula: \( DT = \frac{S_2 - S_1}{H} \), in which \( S_2 \) was heart beat following the \( S_1 \) measured heart beat, and DT meant the time between the closing of the aortic valve and of the closing of the mitral valve in the left ventricle. DP was calculated by multiplying HR by SBP; these values were measured in the last 15 sec in each workload.

### 2.4. Statistical analysis

The data are shown as the mean ± standard deviation. For correlation analysis, we made a simple linear regression analysis, considered the correlation coefficient by Pearson’s coefficient \( r \), and examined any differences in the index by the Wilcoxon method. The level of significance was set at \( p < 0.05 \). Statistical analysis was done with the StatView software program (SAS Institute, Cary Co., USA).

### 3. Results

The heart sounds recorded immediately after the completion of exercise could be measured in all the subjects with clearer waveforms than during the exercise. Figure 2 shows changes in the DP and AHS-1 of all subjects during and immediately after exercise, in which the workload was incremented. For all subjects, HSBP was confirmed in the AHS-1 against workload during and immediately after exercise.

Figures 3 and 4 show relationships between AHS-1 during and immediately after exercise, and between DT during and immediately after exercise, respectively. A high correlation was observed between the values during and immediately after exercise for individual subjects (AHS-1, \( r \) = from 0.957 to 0.993; DT, \( r \) = from 0.951 to 0.993). Furthermore, as seen in Figures 5a and 5b, a high correlation was observed overall for the subjects (AHS-1, \( r \) = 0.979; DT, \( r \) = 0.981).

### 4. Discussion

The results of this study clarified that the AHS-1 and the DT during exercise can be estimated from a phonocardiogram and an ECG that is recorded immediately after exercise. The phonocardiogram can provide an important clue regarding the effect of exercise on the heart. Obara et al. (2005) suggested that the AHS-1 during exercise is an index of the LA. In addition, the sufficient to avoid decrease in the ratio of AHS-1 and DT during exercise. The decrease in the ratio of DT during exercise it can cause myocardial ischemia can myocardial ischemia (Ferro et al. 1995) and it can be calculated from the timing of S1 and S2 of the phonocardiogram. Namely, if a clear phonocardiogram can be recorded during exercise, it is possible to judge aerobic exercise will be safe. However, it is not easy to record a clear
phonocardiogram during exercise. Failure to properly fasten the heart sound microphone, detachment of the adhesion side due to perspiration, increased frequency of respiration, the friction of clothes, and increased body movement may cause noises, and when high intensity exercise is performed, the noises may be incorporated on the phonocardiogram, and moreover if the microphone fails off the heart sounds may not be recorded.

Obara et al. (2005) devised a fastening method and attempted to record phonocardiograms during exercise on a cycle ergometer. They reported significant relationships among AHS-1, LA and DP. However, we experienced several cases in which measurement was difficult due to noise effects of especially when walking or running on the treadmill, even though we used a method similar to that reported by Obara et al. The causes of such noises may disappear if the recordings

Figure 2 Changes in the AHS-1 during and immediately after exercise, and in the DP during exercise. ○, AHS-1 during exercise; , AHS-1 immediately after exercise; △, the DP during exercise.

Figure 3 Relationship between AHS-1 during and immediately after exercise.
are taken immediately after exercise. In addition, although the amplitude of the heart sound is affected by the movement of the thorax with the breathing, it is possible to stop breathing immediately after exercise and then to measure AHS-1 more clearly. Takei et al. (1997) have suggested that holding the breath may induce myocardial ischemia due to increases in HR and BP accompanied by increases in the thoracic and abdominal internal pressures. However, they observed that HR and BP tended to decrease during aerobic exercise. Indeed, we observed DP decreased when the subjects held their breath immediately after the exercise (data were not shown).

Measuring heart sounds after exercise is an easy and very inexpensive technique in comparison to LA or gas analyses. If the heart sounds are measured immediately after exercise in each stage in an intermittent type of graded exercise test, we can estimate the LT and DT against the workload. Furthermore, if the DT fraction against the RR interval is more than 50%, we can then estimate that the exercise stress may not cause myocardial ischemia because the ischemic threshold of severe coronary stenosis in patients is less than 50% of the DT (Ferro et al., 1995).

In conclusion, the measurement of heart sounds immediately after exercise is less affected by noises.
than doing during exercise. Since measuring DT by phonocardiographic recordings has been reported to be a reliable noninvasive technique (Boudoulas et al., 1979), we believe that this method, in addition to the use of ECG and BP monitoring, may be useful for prescribing optimal exercise intensity.

Acknowledgement

This study was partly supported by the Grant-in-Aid for Exploratory Research 18650202 and the Grant-in-Aid for Scientific Research (A) 19200049 from the Japan Society for the Promotion of Science, and a Global FU Program grant by Fukuoka University.

References


