Research on First Heart Sound and Second Heart Sound Amplitude Variability and Reversal Phenomenon--A New Finding in Athletic Heart Study

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Abstract

First heart sound (S1) and second heart sound (S2) amplitude ratio (S1/S2) reflects the relationship between the cardiac contractility and the peripheral resistance. Between consecutive cardiac cycles, there is almost always a variation in the amplitude of the S1 and S2. The goal of our study was to get an insight into athlete cardiac responses to hypoxia conditions by studying S1/S2 variability. A breath-holding phonocardiogram test (BHPCGT) was designed for inducing a hypoxic condition. When performing the BHPCGT in 116 subjects (71 athletes and 45 non-athletes), a phenomenon, reversal of S1/S2, was found in 13 samples (6 Full-reversal, 7 Partial-reversal). There were 4 (5.63%) reversed samples from athletes controlled with 9 (20%) from non-athletes. *t*-test statistic results showed that 51 (71.83%) samples from athletes and 33 (73.33%) from non-athletes had significant differences ($p < 0.05$) between the two conditions. We suggest that holding breath does have influence on the function of heart to some extent, and the tolerance to hypoxia might be better in athletes than in non-athletes. The reversal of S1/S2 may have a significant value in assessing cardiac reserve, studying cardiac fatigue and observing heart responses to hypoxia. However, further large-sample and multicentre studies are still needed.

Keywords: Cardiac reserve (CR), Phonocardiogram (PCG), Heart sound, Reversal phenomenon

1. Introduction

One of the most important physiological bases of athletes' fitness and exercise performance is cardiac function, especially cardiac contractility and cardiac reserve. There is a 20-fold difference between the most impaired cardiac function and that of the fittest person [1]. Cardiac function includes multiple aspects: inotropism, chronotropism, and dromotropism. An ideal method to measure cardiac function would be able to simultaneously reveal multiple aspects of cardiac function, especially being sensitive to changes in inotrophy, safe and easy to apply, and proven to be useful in ordinary settings. Electrocardiography is the best technique to reveal chronotropism and dromotropism, but cannot be used to evaluate inotropism. The end systolic stiffness [2] measured by echocardiography is the optimal evaluate the inotrophic indicator to changes, but has not yet been used widely. Ejection fraction is easy to apply, but not very sensitive to inotrophic changes [3]. Cardiac blood pool imaging has high sensitivity and specificity, but is expensive and difficult to popularize. Peak oxygen consumption, considered the gold standard, is noninvasive, objective and reliable but is influenced by respiratory function, and inappropriate for use in ordinary settings. Cardiac catheter method is objective and quantitative, but invasive, needs to be performed in a special laboratory, and is inappropriate for repetitive and routine use.

Studies have shown that there is a very close relationship between the amplitude of the first heart sound and cardiac contractility [4,5], implying a way to resolve the abovementioned problems. A study by Hansen et al. [4] showed that changes in the amplitude of the first heart sound are closely related with the maximum rate of rise of left ventricular pressure ($r = 0.9551$, $P < 0.001$). Therefore, the change trend of the amplitude of the first heart sound (S1) can be used to evaluate cardiac reserve and cardiac endurance. Xiao et al. [6] introduced a concept "cardiac contractility change trend (CCCT)", which was defined as the increase of the first heart sound amplitude after accomplishing different

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exercise workloads with respect to the amplitude of the first heart sound recorded at rest. They also conducted systematic research in various populations by using phonocardiogram exercise testing (PCGET), and concluded that the first heart sound amplitude change trend provides a non-invasive assessment of cardiac reserve (CR) [6-9].

However, there are many factors that can influence the absolute amplitude of heart sound, such as gender, age, the thickness of the chest wall, the distance between the heart and the chest wall, physiopathologic conditions, the emotions of different subjects, different postures, respiratory depth, the position of sensor on the chest wall, etc. So, the absolute amplitude of S1 cannot be used as an indicator for evaluating cardiac contractility. In order to resolve this problem, Xiao et al. [7] brought forward the use of a relative value method to introduce a new group of indicators, including the ratio of the first heart sound amplitude to the second heart sound amplitude (S1/S2), as an assessment of the heart function and peripheral circulation, the ratio of the S1 amplitude at xiphoid area to that at cardiac apex area (T1/M1) for evaluating the relative workload status of the left and right ventricles, and the ratio of diastolic to systolic duration (D/S) for evaluating whether the myocardial perfusion time is sufficient.

Since the amplitude of S2 is a reflection of the peripheral resistance [10], S1/S2 ratio reflects the relationship between the cardiac contractility and the peripheral resistance, including the regulatory capacity of the myocardium under stress. Between consecutive cardiac cycles, there is almost always a variation in the amplitudes of S1 and S2. During a study on S1/S2 variability, when performing the breath-holding phonocardiogram test (BHPCGT) in athletes and non-athletes, a phenomenon, reversal of S1/S2 in some subjects, was found and reported herein.

2. Materials and methods

2.1 Subjects

Two groups of subjects, 116 volunteers in all, were enrolled in this study. The first group of subjects consisted of 71 athletes from physical education department with a mean age of 20.79 ± 1.57 (range 17 to 26), including 51 males and 20 females. The second group consisted of 45 students from general departments with a mean age of 23.64 ± 1.88 (range 20 to 27), including 32 males and 13 females. Subjects of both groups were students from Chongqing University, Chongqing, China.

2.2 Equipment

A cardiac contractility monitor (CCM, developed by Bo-Jing Medical Informatics Institute, Chongqing, China) based on a personal computer was used for this study. The CCM hardware consisted of a phonocardiographic sensor (placed on the subject's precordium) and a heart-sound signal preprocessing box. The software was specifically written for this project, and it included a fundamental heart-sound measurement system which had several end-user-friendly capabilities, such as real-time graphical monitoring during recording and tools for calculating heart rate, S1/S2, D/S and some other parameters. The development environment was Visual Basic 6.0 and the Access relational database, with Windows 98/2000/XP (Microsoft, Inc.) operating platform. This equipment gives a flat frequency response in the whole frequency range of usual heart sounds (from 30 to 800 Hz). The heart-sound signals were recorded through the sound card of PC at sampling frequency of 11025 Hz.

2.3 Methods

We firstly recorded subjects' phonocardiograms (PCGs) at rest, and then recorded in a breath-holding condition for about 24 seconds or less at end-expiration. To get subjects into a hypoxic state as soon as possible, all subjects were required to exhale the air out to the best of their abilities before the BHPCGT. A trained researcher placed a PCG sensor on the subject's precardium. In order to avoid human-induced errors, every testing operator was required to press the sensor with similar strength against the same area of each volunteer's chest in two conditions. All subjects were not allowed to do any hard physical work in the half hour or more preceding testing, and they had been told to keep quiet and relaxed during the test. Most of the subjects took the test in our Heart Sound Collecting Laboratory supported by Chongqing University and Bo-Jing Medical Informatics Institute, and a few recordings from athletes were collected in the physical education department office. Both the laboratory and the office were in Chongqing University, Chongqing, China.

The S1/S2 ratio had a dimensionless value. When calculating the S1/S2, we used the amplitude of S1 divided by the amplitude of S2 in each cardiac cycle. The heart sound amplitudes can be obtained by clicking at the maximum wave peak of each S1 and S2, and the S1/S2 can be calculated automatically by the CCM heart-sound analysis software. S1/S2 ratio was logged for each sample for each subject. Two-tailed homoscedastic *t*-test was applied on the S1/S2 data of each individual to find statistically significant parameters under these two statuses for *p*-values.

By studying the data collected, we found that some of the subjects' S1/S2 reversed in the breath-holding condition. This means that the amplitudes of S1 were higher than those of S2 at the beginning of the BHPCGT, but the amplitudes of S1 were shorter than those of S2 at the end of the breath-holding test. We defined Full-reversal as being that in the first 5 cardiac cycles, all of the S1/S2 $\geq$ 1, while in the last 5 cardiac cycles, all of the S1/S2 $<$ 1. And the Partial-reversal was defined as being that in the first 5 cardiac cycles, 3 or 4 of the S1/S2 $\geq$ 1, and in the last 5 cardiac cycles 3 or 4 of the S1/S2 $<$ 1. Other cases were defined as Non-reversal. *t*-test was then applied for statistical analysis of the S1/S2 variance between the normal respiration and the breath-holding state in all subjects.

3. Results

A prototype of Full-reversal (during breath-holding) is presented in Figure 1 (the first 5 cardiac cycles) and Figure 2 (the last 5 cardiac cycles).

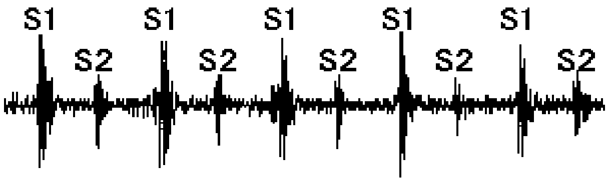

Figure 1. First five cardiac cycles of a Full-reversal PCG recording (non-athlete, 20 year-old male). The S1 amplitudes at the beginning several cardiac cycles of this sample are obviously greater than S2.

In Fig. 1, the amplitudes of S1 are obviously higher than those of S2. But in Fig. 2, the S1s are all smaller in amplitude than S2s. The PCGs of Figs. 1 and 2 are from a non-athlete's sample in breath-holding condition. We traced the starting time of reversal phenomenon in this sample, which appeared at 16.508 seconds. In the rest condition, the S1/S2 ratios showed little variability from beginning to the end of the PCG recording for this subject.

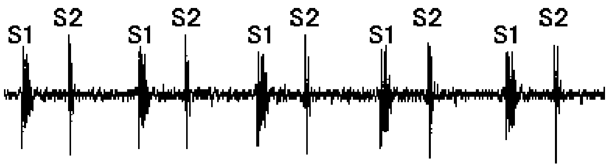

Figure 2. Last five cardiac cycles of the same Full-reversal PCG recording (non-athlete, 20 year-old male). The S1 amplitudes are becoming less than the S2 during the last several cardiac cycles in the same sample.

The S1/S2 reversal data of the 71 athletes and the 45 healthy non-athletes in breath-holding condition are shown in Table 1. There were 13 reversed samples altogether, consisting of 6 Full-reversal (1 from athletes, 5 from non-athletes) and 7 Partial-reversal (3 from athletes, 4 from non-athletes). There was only 1 Full-reversal, making up 1.14%, in all 71 athletes' breath-holding samples, while 5 (11.11%) appeared in the 45 non-athletes' recordings. The only Full-reversal athlete was a twenty year-old male, who had a history of systolic murmur. His sample reversed at the point of 14.97 s. There were 3 (4.22%) Partial-reversal in the athlete group, and 4 (8.89%) were found in the control group.

Table 1. S1/S2 reversal data of both groups under the breath- holding state.

<table>
<tr><th></th><th>Full-reversal</th><th>Partial-reversal</th><th>Non-reversal</th></tr>
<tr><td rowspan="2">Athletes</td><td>1 (1.41%)</td><td>3 (4.22%)</td><td>67</td></tr>
<tr><td colspan="2">4 (5.63%)</td><td>(94.37%)</td></tr>
<tr><td rowspan="2">Non-athletes</td><td>5 (11.11%)</td><td>4 (8.89%)</td><td>36</td></tr>
<tr><td colspan="2">9 (20%)</td><td>(80.00%)</td></tr>
<tr><td>Summary</td><td>6 (5.17%)</td><td>7 (6.04%)</td><td>103 (88.79%)</td></tr>
</table>

*Full-reversal was defined as being that in the first 5 cardiac cycles, all of the S1/S2 ≥ 1, while in the last 5 cardiac cycles, the S1/S2 < 1. Partial-reversal was defined as being that in the first 5 cardiac cycles, 3 or 4 of the S1/S2 ≥ 1 and in the last 5 cardiac cycles, 3 or 4 of the S1/S2 < 1. Other cases were defined as Non-reversal.

Table 2 shows the *t*-test data of the two groups in these two conditions. A p value < 0.05 was accepted as significant difference. The table shows that 51 (71.83%) samples from athletes had significant differences during the breath-holding compared with the normal respiration status, while 20 (28.17%) did not. And there were 33 (73.33%) samples from non-athletes who had significant differences, but 12 (26.67%) did not accordingly.

Table 2. *t*-test statistical data of S1/S2 ratio under two conditions in two groups.

Subjects	Significant difference	No significant difference
Athletes	51 (71.83%)	20 (28.17%)
Non-athletes	33 (73.33%)	12 (26.67%)
Total	84 (72.41%)	32 (27.59%)
p	< 0.05	≥ 0.05

4. Discussion

Breath-holding induces a condition of hypoxia, and the ventricular contraction (reflected by S1 in PCG) would be suppressed while the pulmonary arterial pressure and pulmonary vascular resistance (peripheral resistance, reflected by S2) would increase in this condition. That might be the reason of the falling for S1s and the raising of S2s, which finally results in the reversal of S1/S2.

As seen from Table 1, the reversal phenomenon of S1/S2 (Full-reversal and Partial-reversal) existed in breath-holding condition in both the athlete and the non-athlete groups. Though the age and body-mass index (BMI) were of significant differences between these two groups, as shown in *t*-test results, the proportion of reversed S1/S2 in non-athlete group was much higher than that in athlete group (20% vs. 5.63%). This result may suggest that tolerance to hypoxia is better in athletes than in non-athletes.

As Table 2 presents, the significant differences in ratio of S1/S2 between the two conditions in non-athletes was slightly higher than that of the athletes (73.33% vs. 71.83%, $p < 0.05$). The amplitudes of S1 and S2 had a very sensitive response to hypoxia, for up to 72.41% of the samples had significant differences between the rest and the breath-holding conditions.

Douglas et al. [11] reported that prolonged competitive exercise may result in alterations in systolic and diastolic left ventricular performance, but the alterations returned to baseline after 1 to 2 days' recovery. The rapid reversal of all changes suggested "cardiac fatigue". In our first day of testing, two athletes' S1/S2 reversed, one of them had had a competitive activity half an hour before, and the other had a history of systolic murmur. Both of them were required to take a second test after rest for 3 days. Three days later, the after-training athlete has returned to normal, and the S1/S2 of the other, who had a history of systolic murmur, was still reversed. Based on Douglas et al.'s study, we considered that people with cardiac fatigue and cardiac murmur might have a trend of quick S1/S2 reversal in BHPCGT.

From the studies of Douglas et al. [11] and our team, the status of transiently reduced function of the heart in response to a highly intensive activity can be defined as cardiac fatigue. In the case of our study, the occurrence of cardiac fatigue may be due to the superimposition of two effects, one of which is that the oxygen debt after the strenuous exercise has not disappeared completely, leading to a decrease in cardiac contractility, and the other of which is that BHPCGT inevitably induces a hypoxic state, also leading to a decrease in cardiac contractility.

Studies of Zhou et al. [12] showed that "oxygen reserve capacity" and "cardiac reserve capacity" were better in Tibetan (high-altitude) natives than in the Han (low-altitude) natives. The researchers suggested that physical work capacity was greater in the Tibetan group. In our studies, the S1/S2 ratios of a few individuals did not reverse in BHPCGT at first, but their samples reversed when taking the test continuously 2 or 3 times, with interval breaks less than 60 s. These individuals were supposed to have better oxygen reserve capacities than the people whose sample reversed for taking the BHPCGT once. For a similar reason, we suggest that the S1/S2 variability in low oxygen condition induced by breath-holding might be an indicator of cardiac reserve and physical work capacity.

5. Conclusion

The cardiac contractility and heart sound relationship detection can be a safe, easy technique, and would be able to simultaneously detect heart rate and cardiac contractility and preliminarily observe the rhythm of the heart. Based on our study and the previous studies discussed above, we can conclude that breath-holding does have influence on the function of heart to some extent. The reversal of S1/S2 may have a significant value in assessing cardiac reserve, studying cardiac fatigue and observing heart responses to hypoxia. Moreover, BHPCGT can be used as a new method for evaluating cardiac function in both athletes and non- athletes. However, our small-sample researches on S1/S2 variability are now at a primary stage, and there are still many limitations (e.g. the age and BMI *t*-test differences). So, further large sample and multicentre studies are still needed.

Acknowledgements

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