Study of the Effect of Physical Stress on Coronary Flow Velocity Using Transthoracic Pulse Doppler Echocardiography

HIROSHI MARUOKA, RPT, PhD1), KOICHI KOMAKI, MD, PhD1), KAZUHISA INOUE, RPT1)

1)School of Health and Social Services Saitama Prefectural University:
820 San-nomiya, Koshigaya, Saitama 343-8540, Japan.
TEL +81 048-973-4180 E-mail: maruoka-hiroshi@spu.ac.jp

Abstract. The relationship between muscle stress (MS) or exercise stress (ES) was examined in 20 healthy young volunteers (all male, 22.9 ± 4.8 years old, mean ± SD) through cardiopulmonary exercise testing and coronary flow velocity (CFV). A heart lung function measuring system was used to conduct expiration gas analysis through isokinetic testing, a training system for MS and a treadmill for ES. CFV was measured using an ultrasound diagnostic device before and after MS and ES loadings. CFV showed a significant increase for both MS and ES (p<.01 for both), and rate pressure product (RPP) similarly showed a significant increase (p<.001 for both). The relationship between CFV and expiration gas analysis etc., showed weak correlation only between CFV after loading MS and knee extension muscle strength (r=.56, p<.01). This indicates that CFV increases with ES and MS. Nonetheless, since no correlation was observed between CFV and RPP, further examinations are required with an increased number of volunteers.

Key words: Physical stress, Coronary flow velocity, Transthoracic pulse Doppler echocardiography

INTRODUCTION

Traditionally, measurement of coronary flow velocity (CFV) has only been possible through heart catheterization, which is an invasive test.

Recently, non-invasive measurement has been enabled, through the development of transthoracic pulse Doppler echocardiography for detecting and measuring slow speeds1). This test is characterized by measurements that are easily repeatable, and continuous observation is also possible for exercise loading2).

However, physical stress such as exercise as well as mental stress are said to be factors in increasing CFV2, 3). Kondou N et al. have reported that CFV under exercise loading increases steadily, and correlates with rate pressure product (RPP)2). Further, Hambrecht R. and others have reported improved CFV in coronary artery disease patients after 4 weeks of exercise training using an ergometer4).

Nevertheless, although simultaneous use of muscle training in cardiac rehabilitation is becoming widespread5), there have been no studies of the effect of muscle stress (MS) on CFV.

Therefore, in this report we studied the effect of physical stress resulting from MS and exercise stress (ES) through cardiopulmonary exercise testing (CPX) on CFV.

METHODS

Participants

The subjects were 20 healthy young volunteers (all male, 22.9 ± 4.8 years old, mean ± SD). Instances that were impossible to record for reasons...
such as somatotype were MS:1 and ES:3 volunteers. Before carrying out the test, the purposes and procedures were orally explained and the subjects’ consent for participation was obtained.

**Protocol**

A flow diagram of the Test is shown in Fig. 1. Sufficient rest time was taken before carrying out MS and ES. An automatic sphygmomanometer on the cuff was used during measurement of MS and ES to measure blood pressure and heart rate, and to calculate RPP.

1) Muscle stress

MS was carried out 10 times × 5 sets (60°/sec) on the right knee using an isokinetic testing and training system (BIODEX SYSTEMS 3, Sakai Iryo Co.), and knee extension peak torque was calculated. Then, the average peak torque value was divided by weight to derive the knee extension muscle strength. The standard measurement posture for MS and CFV was the supine position.

2) Cardiopulmonary exercise testing

Cardiopulmonary exercise testing was measured using the ramp loading method as a symptom limit. A treadmill was used as the tool for exercise loading and a protocol of linear loading, increases every minute after a 3-minute warm-up period, was applied. A stress system was employed during exercise loading, with heart rate and arrhythmia monitored using a 12-lead ECG, and blood pressure taken every minute with a STBP-780 (Nihon Colin).

Criteria for termination of the loading test included leg fatigue, dyspnea, poor blood pressure response and a heart rate considered too high for the participants age. Expiration gas analysis was performed using the breath-by-breath method and a heart lung function measuring system (Vmax 29, Sensor Medics Co.). The anaerobic threshold (AT) was determined mainly by the V-slope method in reference to the changes in ventilation equivalent against either the oxygen uptake or the carbon dioxide discharge quantity. The peak oxygen uptake (Peak VO₂) was defined as the average value during the last 30 seconds of loading and was used, together with AT, as an index of exercise capacity.

3) Transthoracic pulse Doppler echocardiography

Using an ultrasound diagnostic device (Vivid7, GE Medical System Co.), a 7 MHz probe was placed on the left side of the lower chest to detect the anterior descending branch of the left coronary artery peripheral region using the 2D Doppler method. Sampling took place in the detected region and CFV was measured using the pulse Doppler method. As shown in Fig. 2, the maximum flow in the spectrum analysis chart was taken as max CFV. CFV was measured before and after MS and ES.

4) Statistics

The values before and after the loading test for CFV and RPP were compared using the paired t-test.

Pearson’s correlation coefficient was used to examine the relationship between CFV and
expiration gas analysis, knee extension muscle strength and RPP. SPSS (Ver. 11.5 for Windows) was used for statistical analysis. All results were expressed as the mean ± S.D. and a p-value of less than 0.05 was considered statistically significant.

RESULTS

**CFV**

CFV was measured on the coronary flow spectrum analysis image before and after the loading test (Table 1). It showed a significant increase under both MS and ES: 0.15 ± 0.04 m/sec before the loading test and 0.19 ± 0.04 m/sec after, and 0.15 ± 0.03 m/sec before the loading test and 0.21 ± 0.07 m/sec after, respectively (p<.001 for both).

**RPP**

RPP showed a significant increase under both MS and ES: 7.4 ± 1.4 × 10³ beat · mmHg before the loading test and 10.3 ± 2.2 × 10³ beat · mmHg after; and 9.6 ± 0.4 × 10³ beat · mmHg before the loading test and 29.5 ± 0.9 × 10³ beat · mmHg after, respectively (p<.001 for both) (Table 1).

Table 1. Comparison of Pre-stress and Post-stress coronary flow velocity and rate pressure product

<table>
<thead>
<tr>
<th></th>
<th>Pre-MS</th>
<th>Post-MS</th>
<th>Pre-ES</th>
<th>Post-ES</th>
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<tbody>
<tr>
<td>CFV (m/sec)</td>
<td>0.15 ± 0.04</td>
<td>0.19 ± 0.04</td>
<td>0.15 ± 0.03</td>
<td>0.21 ± 0.07</td>
</tr>
<tr>
<td>RPP (× 10³ beat · mmHg)</td>
<td>7.4 ± 1.4</td>
<td>10.3 ± 2.2</td>
<td>9.6 ± 0.4</td>
<td>29.5 ± 0.9</td>
</tr>
</tbody>
</table>

CFV: coronary flow velocity, RPP: rate pressure product. Abbreviations as in Fig. 3. **: p<0.01, ***: p<0.001.

Relationship between CFV and expiration gas analysis etc.

The relationship between CFV and expiration gas analysis, knee extension muscle strength or RPP showed only a weak correlation between CFV and knee extension muscle strength after the loading test under MS (r=.56, p<.01) (Fig. 4) (Fig. 5).

DISCUSSION

The aim of this research was to examine the relationships between CFV and physical stress caused by MS and ES. This relates to research on the possibility of assessing CFV from muscle strength or expiration gas analysis, and further examines the influence of training through MS etc. on CFV. Furthermore, it is of clinical importance for exercise prescription, and for setting the stress

![Image of transthoracic pulse Doppler echocardiography: Pre-stress and Post-stress comparisons. Pre-MS: before muscle stress; Post-MS: after muscle stress; Pre-ES: before exercise stress; Post-ES: after exercise stress.](image)
strength under physical therapy.

**Effect of physical stress on CFV and RPP**

Goldberg et al. have reported that physical stress through exercise etc., increases epinephrine and norepinephrine concentration in the blood, thus raising RPP and cardiac output\(^8\).

Moreover, rise of RPP is reported to be caused by the decline of parasympathetic nerve activity following increase of exercise strength and increase of sympathetic nerve activity\(^9\). The present research raised the question of whether increase of RPP through physical stress under ES and MS is a change via activation of sympathetic nerves.

CFV is affected by mental stress or exercise, and heart rate, drugs, food and others\(^2, 3, 8, 10, 11\).

Kop et al., using heart catheterization, have reported that although CFV increases before and
after mental stress, no significant change was observed in coronary artery diameter\(^3\). The increase of CFV under ES and MS in the present research seems to show the possibility of an increase in coronary flow quantity without any change in coronary artery diameter. That is, physical stress caused activation in sympathetic nerves, resulting in an increase in heart muscle oxygen consumption, and an increase in coronary flow quantity is also likely to have resulted in an increase of CFV. Moreover, the reported relationship between the pattern of CFV and prognosis prediction\(^{11}\) indicates the necessity of further examination.

**Relationship between CFV and expiration gas analysis, knee extension muscle strength and RPP**

Correlation between CFV and RPP has been observed, and exercise training is reported to improve CFV\(^2, 4\). The values for CFV and RPP in the present report were recorded during rest and immediately after the loading test for both ES and MS. This was probably the cause of the absence of correlation. While Peak \(\text{VO}_2\), i.e. expiration gas analysis, is governed by the cardiopulmonary circulation system or the oxygen utilization ability of skeletal muscles amongst others, the oxygen utilization ability of skeletal muscles is especially important\(^{13, 14}\). Oxygen utilization ability, or artery-vein oxygen difference, increases with short-term exercise, and is reported to play about 50% of the role in increase in oxygen uptake\(^{14}\). The mechanism of oxygen utilization ability includes increase of mitochondria in skeletal muscles or adaptation of the oxidation process following oxidation activity enzyme rise. That is, exercise training is probably, in the same manner as skeletal muscle, related to the increase of oxygen utilization ability in heart muscle cells. In this report, the fact that the CFV value was measured in the rest time and immediately after the loading test for both ES and MS is likely to have been the cause of the absence of correlation with expiration gas analysis.

Further examination is required of CFV and RPP in exercise loading and their relationships with expiration gas analysis.

Yamazaki et al. have reported that knee extension muscle strength showed a positive correlation with Peak \(\text{VO}_2\)\(^{15}\). In the present report, the absence of correlation between knee extension muscle strength and Peak \(\text{VO}_2\) is likely to have been caused by knee extension muscle strength being measured only on the right side. Moreover, to determine the relationship between CFV and knee extension muscle strength, consideration of the analysis method and further examination with an increased number of volunteers is required.

**Study limitations**

This research has some limitations. First of all, easy evaluation of CFV using transthoracic pulse Doppler echocardiography is only available for the anterior descending branch of the left coronary artery peripheral region, and the probability of CFV detection is generally 90–95%\(^6\). It is thus difficult to visualize in some subjects. Although a method is available for increasing detection sensitivity using drugs, it is a problem awaiting solution. Also, physical stress under MS is influenced by the short-term effect (difference of loading test strength or number of times) and long-term effect (training for a fixed period etc.), which is a problem awaiting further consideration with an increased number of volunteers.

**CONCLUSIONS**

The influence of physical stress on CFV under MS and ES was examined. CFV showed a significant increase. This indicates that CFV increases with MS as well as with ES.

**REFERENCES**


