Studies on Coronary Circulation in Coronary Sclerosis

Yuji Kojima, M.D.

In coronary sclerotic patients with a fixed coronary vascular resistance, coronary blood flow is to be directly regulated by perfusion pressure. In this report, an analysis of perfusion pressure was carried out regarding coronary blood flow, myocardial oxygen consumption, and myocardial oxygen supply. Fourteen patients with coronary sclerosis were studied. In resting state, mean diastolic pressure calculated from brachial arterial pressure curve was significantly related with coronary blood flow. The product of mean diastolic pressure and heart rate was more linearly correlated with coronary blood flow. The relation of these factors with coronary blood flow was discussed in reference to the myocardial oxygen consumption.

Also, mean diastolic pressure was similarly correlated with myocardial oxygen supply. In this result the author concludes that diastolic mean pressure is more important factor to regulate coronary blood flow or myocardial oxygen supply in coronary sclerotic patients.

STUDIES on coronary circulation in human beings by coronary sinus catheterization technic was introduced by Bing1 (1949). Thereafter, several clinical investigations were reported, but studies on coronary sclerosis did not seem to be sufficient.

Recently, the fundamental determinant of coronary blood flow has been appreciated; the changes in coronary flow reflect only changes in myocardial oxygen consumption.2)-6),13)

Generally, the most important factors of hemodynamic determinants of coronary blood flow are coronary vascular resistance and perfusion pressure of the coronary vessels.

In coronary vascular disease, coronary vascular resistance is either fallen to a minimum value indicating maximal arteriolar dilatation,7) or is fixed presumably due to coronary arterial sclerosis.8),9)

Therefore, in coronary patients with a fixed coronary vascular resistance, coronary blood flow is directly augmented by an increase of perfusion pressure.9)

At this point, this paper presents such an analysis of perfusion pres-
sure in detail, regarding coronary blood flow, myocardial oxygen consumption, or myocardial oxygen availability.

**Materials and Methods**

Fourteen subjects with coronary arterial disease were chosen for analysis, including 13 males, 1 female, aged from 34 to 79 (average aged 55). Most of them were hospitalized except a few of the outpatients.

They consisted of 2 with angina pectoris, 10 with ischemic ST-T changes in resting electrocardiograms or with positive standard Master's two step test.

One with auricular fibrillation and another one with frequent premature ventricular contractions were also included in this series, since the evidence of another cause was excluded.

Coronary sinus catheterization was carried out on each subject in the fasting state after at least 8 hours. Coronary blood flow was measured by nitrous oxide desaturation technic.

Blood pressure was recorded by the puncture of the brachial artery with strain gauge transducer MP-3 (Nihon Kohden) in all cases.

**Results**

The individual data of coronary hemodynamics and blood gas analysis in 14 cases were shown in Table I.

The statistical values of the pressure-flow, pressure myocardial oxygen consumption or pressure-myocardial oxygen supply relationship were illustrated in Table II.

1) Coronary blood flow (CBF)

a) Correlations between CBF and systolic or diastolic blood pressure

As shown in Figs. 1 and 2, CBF was correlated with diastolic pressure \((r=0.72, p<0.01)\) but not with systolic pressure.

As shown in Figs. 3 and 4, when these pressures were multiplied by heart rate \((HR)\) which was measured at the same time, CBF was correlated with systolic pressure \(\times HR\) \((r=0.54, p<0.05)\) and more linearly related with diastolic pressure \(\times HR\) \((r=0.73, p<0.01)\).

b) Correlations between CBF and mean blood pressure (MP)

There was no definite correlation between CBF and mean blood pressure and also mean blood pressure \(\times HR\) i.e. Katz's index.

c) Correlations between CBF and mean systolic pressure (MSP) or mean diastolic pressure (MDP)

Mean systolic or diastolic pressure which was calculated from the arterial pressure curve was evaluated in connection with CBF.

In respect of MSP, no remarkable relationship between MSP alone and
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CBF=Coronary blood flow ml./100 Gm./min.  MOC=Myocardial oxygen consumption ml./100 Gm./min.  MOS=Myocardial oxygen supply ml./100 Gm./min.  O₂ₐ=Arterial blood oxygen content Vol. %.  O₂ₙ=Coronary venous blood oxygen content Vol. %.  ΔO₂=Coronary arteriovenous oxygen difference Vol. %.  O₂ExR=Myocardial oxygen extraction ratio %.  RQ=Myocardial respiratory quotient.  HR=Heart rate/min.  SP=Systolic blood pressure mm.Hg.  DP=Diastolic blood pressure mm.Hg.  MP=Mean blood pressure mm.Hg.  MSP=Mean systolic pressure mm.Hg.  MDP=Mean diastolic pressure mm.Hg.  TTI=Tension time index (Sarnoff) mm.Hg.sec./min.  DD=Diastolic duration time sec.
Table II. The Statistical Values of the Correlations between Coronary Blood Flow, Myocardial Oxygen Consumption, Myocardial Oxygen Supply, and Blood Pressure and Heart Rate

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CBF was observed, but MSP×HR and MSP×HR×systolic duration time (TTI, Sarnoff)\(^{13}\) correlated with CBF \((r=0.56, \ p<0.05; \ r=0.58 \ p<0.05 \ \text{respectively})\) (Fig. 5).

On the other hand, CBF was significantly related with mean diastolic pressure ranged from 70 to 153 mm.Hg \((r=0.76, \ p<0.01)\) (Fig. 6).

Furthermore, a really good correlation between CBF and MDP × HR was also recognized \((r=0.79, \ p<0.001)\) (Fig. 7).

MDP × HR × diastolic duration time per min. showed only a tendency to increase with the increment of CBF.

2) Myocardial oxygen consumption (MOC)
Fig. 1. Relationship of coronary blood flow to systolic blood pressure.

Fig. 2. Relationship of coronary blood flow to diastolic blood pressure.

Fig. 3. Relationship of coronary blood flow to systolic pressure × heart rate.

Fig. 4. Relationship of coronary blood flow to diastolic pressure × heart rate.
Fig. 5. Relationship of coronary blood flow to mean systolic pressure × heart rate.

Fig. 6. Relationship of coronary blood flow to mean diastolic pressure.

Fig. 7. Relationship of coronary blood flow to mean diastolic pressure × heart rate.

Fig. 8. Relationship of myocardial oxygen consumption to systolic blood pressure.
Fig. 9. Relationship of myocardial oxygen consumption to diastolic blood pressure.

Fig. 10. Relationship of myocardial oxygen consumption to tension time index.

Fig. 11. Relationship of myocardial oxygen supply to mean diastolic pressure.

Fig. 12. Relationship of myocardial oxygen supply to mean diastolic pressure x heart rate.
MOC was recognized already as the most important determinant of CBF by many investigators.\textsuperscript{2,6,13)\textsuperscript{13}}

In this report, MOC was analysed in the relation with blood pressures.

a) Correlations between MOC and systolic or diastolic pressure

As shown in Figs. 8 and 9, MOC was correlated really with diastolic pressure ($r=0.76$, $p<0.01$), but not with systolic pressure.

Furthermore, MOC was correlated with both of systolic pressure $\times$ HR ($r=0.55$, $p<0.05$) and diastolic pressure $\times$ HR ($r=0.72$, $p<0.01$) respectively.

b) Correlations between MOC and mean blood pressure (MP)

Mean blood pressure was correlated with MOC ($r=0.57$, $p<0.05$), but MP $\times$ HR i.e. Katz's index had only a trend to relate with MOC.

c) Correlations between MOC and mean systolic pressure (MSP) or mean diastolic pressure (MDP)

There was no marked relationship between mean systolic pressure or MSP $\times$ HR and MOC, but MOC was shown to correlate with tension time index ($r=0.64$, $p<0.02$) (Fig. 10). On the other hand, MOC was significantly related with both MDP ($r=0.65$, $p<0.02$) or MDP $\times$ HR ($r=0.72$, $p<0.01$).

3) Myocardial oxygen supply (MOS)

a) Correlations between MOS and systolic or diastolic pressure

MOS showed such a fairly good correlation with diastolic pressure ($r=0.79$, $p<0.001$), or diastolic pressure $\times$ HR ($r=0.72$, $p<0.01$) as shown in CBF and MOC was observed (Table II).

However, MOS was related only with systolic pressure $\times$ HR ($r=0.56$, $p<0.05$), but not with systolic pressure alone.

b) Correlations between MOS and MSP or MDP

As shown in Figs. 11 and 12, MOS was significantly correlated with MDP ($r=0.80$, $p<0.001$) and with MDP $\times$ HR ($r=0.72$, $p<0.01$).

In contrast, MOS had no relation with MSP, but with MSP $\times$ HR ($r=0.55$, $p<0.05$).

**DISCUSSION**

Many experimental and clinical observations are agreed that myocardial oxygen consumption is the fundamental determinant of coronary blood flow. The determinants of myocardial oxygen consumption have gradually been clarified.

In isolated heart experiments,\textsuperscript{13)-16)\textsuperscript{16}} myocardial oxygen consumption was correlated both with pressure generated by the ventricle and with its frequency.

In the clinical observation by means of coronary sinus catheterization, Lombardo\textsuperscript{8)} observed the increase of coronary blood flow accompanied by an
increase of blood pressure in one patient suffering from angina pectoris, due to a fixed resistance of the coronary vascular bed.

In 7 coronary sclerosis Gorlin\(^9\) also reported that with a fixed coronary arteriolar resistance and fixed flow, oxygen supply is necessarily limited unless flow is augmented by an increase in perfusion pressure or in oxygen extraction ratio.

At rest, the ratio of myocardial oxygen extraction in coronary patients maintains approximately constant showing normal value\(^6\) or slightly increased,\(^16\) unless the myocardial oxygen extraction percentage is elevated by an exercise.\(^6\)

Therefore, in coronary patients the coronary blood flow may be primarily regulated by perfusion pressure.

In experimental observations, several investigators reported that effective perfusion pressure,\(^17\) mean systemic pressure,\(^18\) or coronary driving pressure\(^19\) is mainly correlated with coronary blood flow.

In this report, mean diastolic pressure or mean diastolic pressure × heart rate showed a better correlation with coronary blood flow than mean systolic pressure or mean systolic pressure × heart rate.

It is known that coronary inflow occurs mainly during diastole in the resting state, and according to Gregg's observation\(^20,21\) the left coronary inflow during diastole is about 75 per cent of coronary flow. Therefore, diastolic hemodynamics assume major importance as determinants of coronary flow.\(^22\)

It is readily expected that the coronary blood flow correlates with the diastolic hemodynamic factor more linearly than with the systolic one, as shown in this report. It is to be emphasized that a good correlation coefficient between coronary blood flow and mean diastolic pressure multiplied by heart rate was proved in this investigation.

Blood pressure and heart rate are so important factors to determine myocardial oxygen consumption,\(^15\) that blood pressure × heart rate indicates more directly the oxygen needs of the myocardium than blood pressure alone.\(^23,24\) In another viewpoint, Gregg and coworkers\(^21\) reported that the stroke coronary flow could change considerably without significant alterations of blood pressure and heart rate. However, it is considered that the coronary flow values expressed in per 100 Gm. left ventricle per min, are more readily paralleled with blood pressure × heart rate. There are several reports that coronary blood flow and myocardial oxygen consumption showed significant correlation.\(^5\)–\(^6\)

It is described in these reports that the determining factor of myocardial oxygen consumption, and thus coronary blood flow, is the tension developed by the myocardium per unit of time.
Therefore, Katz's index,23) tension time index (Sarnoff)13) and myocardial tension (Rodbard)12) are proposed as the significantly correlated indices with myocardial oxygen consumption.

Kobayashi10),11) also evaluated these indices regarding to myocardial oxygen consumption, and recognized the positive correlation respectively.

In this study, MOC was proved to correlate not with mean systolic pressure, but with tension time index. It is agreed with Sarnoff's report.13) However, no significant correlation between mean pressure × heart rate (Katz's index) and myocardial oxygen consumption could be observed.

In contrast, myocardial oxygen consumption was correlated with diastolic blood pressure or diastolic pressure × heart rate and mean diastolic pressure or mean diastolic pressure × heart rate.

The myocardial oxygen consumption per unit time is the product of prevailing coronary blood flow and myocardial oxygen extraction per unit of blood. The resting coronary arteriovenous oxygen difference is the highest of all the other organs25) and is considered to be reached to approximately the upper limit of oxygen extraction from the arterial blood.

At resting state, the coronary arteriovenous oxygen difference is kept relatively invariable in healthy and also sclerotic hearts, and the augment of myocardial oxygen consumption is adjusted mainly by the increase of coronary blood flow.26)

Thus, coronary blood flow is a more important factor for the response to an increase of myocardial oxygen consumption rather than the myocardial oxygen extraction. Therefore, myocardial oxygen consumption well correlated with diastolic blood pressure or mean diastolic pressure which was a better determinant of coronary blood flow in this paper.

Then, in the present paper myocardial oxygen supply which was obtained by multiplying the arterial oxygen content by coronary blood flow is examined comparing with blood pressure. Myocardial oxygen supply also showed similar relationship to mean diastolic pressure or mean diastolic pressure × heart rate respectively. As already known, the myocardial oxygen availability also changes in parallel with the myocardial oxygen consumption,3),16),23) or in another word, the subservience of supply to the oxygen needs of the myocardium is pointed out. It was observed that the myocardial oxygen supply was regulated also rather by mean diastolic pressure or mean diastolic pressure × heart rate than those of systolic pressure.

**SUMMARY**

An investigation was carried out to evaluate mainly the influence of blood
pressure and heart rate on coronary blood flow, myocardial oxygen consumption and myocardial oxygen supply by coronary sinus catheterization on 14 cases of coronary sclerosis.

In resting state, mean diastolic pressure calculated from arterial pressure curve was correlated with coronary blood flow significantly.

When mean diastolic pressure was multiplied by heart rate, the relationship with coronary blood flow became to be more linear.

The relation of these factors with coronary blood flow was discussed in reference to the myocardial oxygen consumption.

The similar correlation between mean diastolic pressure or myocardial oxygen supply was also observed.

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