Hemodynamic Evaluation of Ischemic Heart Disease

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SUMMARY

Right and left heart catheterizations were performed on 53 patients with myocardial infarction (10 hours to 7 years after the initial attacks). Twenty-five patients with angina and without infarction as well as 7 patients with pulmonary diseases were evaluated with the same methods.

Right atrial, pulmonary arterial and pulmonary capillary pressures were elevated in the infarction group compared to the angina and pulmonary patients. However, pulmonary capillary pressure was most sensitive to detect the left ventricular dysfunction due to myocardial infarction. Left ventricular stroke work index, maximal dp/dt, and mean circumferential shortening rate were significantly lower in infarction patients compared to angina patients.

The left ventricular dysfunction of infarction patients was mostly encountered in acute period and several years after the initial attacks and was rare between these periods.

Coronary circulation was evaluated with N2O method, however, there was no significant difference in the coronary circulatory disturbances of infarction and angina groups.

The prognosis of the patients was evaluated in terms of pulmonary arterial wedge pressure, left ventricular mean circumferential shortening rate and stroke work index. Seventy-five per cent of those who showed abnormal values in all of these parameters died during the follow-up period of 5–10 years after the measurements. Left ventricular stiffness was assessed with left ventricular diastolic pressure-volume relationship and the stiffer left ventricle showed the worse prognosis.

Additional Indexing Words:
Myocardial infarction Prognostic index Coronary blood flow
Myocardial shortening velocity dp/dt Swan-Ganz catheter

For the last few years, there have been serious investigations on the problems of ventricular dysfunction due to acute myocardial infarction, and newer concepts on pump failure of acute myocardial infarction have been presented.

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However, the spectrum of ventricular dysfunctions induced by coronary obstructive disease is widely scattered from frank effort angina with single vessel disease to intractable heart failure due to far advanced myocardial ischemic changes.\(^5\)

On the other hand, the surgical as well as medical therapeutic interventions have proved to be definitely effective when the candidates for the procedures are selected based on precise functional evaluations of the heart.\(^6\)

Therefore, it is of great importance to assess precisely the every variety of the ischemic heart disease. The present study was undertaken to evaluate the hemodynamic differences of the patients with coronary artery disease of various advancements.

**METHODS**

A total of 85 patients were studied. Fifty-three of them (50 men and 3 women) had well documented history of myocardial infarction and diagnostic electrocardiographic changes, and ranged in age from 38 to 80 (Group I).

Cardiac catheterization was performed at the time of 10 hours to 7 years after the initial attacks. Right heart catheterization was performed on all of them, coronary sinus catheterization was performed on 25 and left heart catheterization was performed on 21 of the Group I patients. Flow-directed, balloon-tipped catheter (Swan-Ganz) was used for acutely ill patients,\(^7\) and trans-septal method was applied for left heart catheterization.\(^8\) Twenty-five patients (20 men and 5 women, 41–69 years old) without history of myocardial infarction and with typical angina pectoris as well as electrophysiological evidences of myocardial ischemia were studied with the same methods as mentioned above (Group II).

Seven patients (7 men, 58–69 years old) with pulmonary diseases were studied as control group (Group III).

Cardiac output and ejection fraction were obtained with dye dilution method,\(^8,9\) coronary blood flow was measured with N\(_2\)O method,\(^10\) and blood gas analyses were done with Van-Slyke apparatus and IL meter.

Right atrial pressure (RAP), pulmonary artery pressure (PAP), pulmonary capillary wedge pressure (PCWP), and left atrial pressure (LAP) were recorded.

In order to evaluate the left ventricular function, stroke work index (SWI)*, left ventricular end-diastolic volume (LVEDV)\(^*,9\) left ventricular maximal dp/dt,\(^11\) and left ventricular mean circumferential shortening rate (MCSR)\(^*\*\*\)\(^12\) were calculated.

As parameters to represent coronary circulation, coronary sinus blood oxygen tension (PcsO\(_2\)), myocardial oxygen extraction coefficient (MOEC)*, and coronary blood flow (CBF) were measured.\(^10\)

The follow-up of the patients was continued for the periods of 5 to 7 years. Exceptions were the patients with myocardial infarction within 24 hours, because cardiac catheterization by flow-directed catheter was introduced 2 years ago.\(^7\)

\[ * \text{SWI} = (\text{stroke index}) \times (\text{LV mean systolic pressure} - \text{LV end-diastolic pressure, or PCWP}) \times 0.0136 \]
** LVEDV = (stroke index) / (ejection fraction)

*** MCSR = $2 \pi \frac{(rd-rs)}{LVET}$

- rd: ventricular radius of end-diastolic period
- rs: ventricular radius of end-systolic period
- LVET: left ventricular ejection time

$+ \text{MOEC} = \frac{(\text{myocardial oxygen consumption})}{(\text{oxygen supply to the heart})}$

RESULTS

The mean and standard error of the mean of RAP, PAP, and PCWP were compared for the Group I, II, and III patients (Fig. 1). The average values of RAP were within normal limits for all of the 3 groups of the patients. The average of PAP was significantly elevated in Group I compared to Group II, but also elevated in Group III. The average values of PCWP were markedly elevated in Group I, moderately elevated in Group II, and stayed within normal range in Group III.

The differences of the PCWP of these 3 groups of the patients were statistically significant.

Left ventricular functions were assessed in terms of LVSWI, dp/dt, and MCSR.

As illustrated in (Fig. 2), these parameters were significantly lower in Group I than in Group II. On the other hand, there were no significant...
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Fig. 2. LV function of ischemic heart disease.

Fig. 3. Coronary circulation of ischemic heart disease.

PCSO₂: oxygen tension of coronary sinus blood.
MOEC: myocardial oxygen extraction coefficient.
CBF: coronary blood flow.

PCSO₂, MOEC, and CBF of these 2 groups (Fig. 3).

The time course of myocardial infarction was evaluated with PCWP (Fig. 4).

The average values of PCWP were elevated in the acute phase and in
the period of more than 3 years after the initial attacks. The PCWP stayed within normal limits between these two periods (<10 mmHg).

Twenty-five % of the patients with elevated RAP (>5 mmHg), 37% of those with elevated PAP (>15 mmHg), and 40% of those with elevated PCWP (>10 mmHg) had cardiac death during the follow-up period (arrhythmia death was excluded).
Fifty % of those with decreased SWI (<40 Gm·M/M²), and 67% of those with decreased MCSR (<4 cm/sec) died. Seventy-five % of those who had abnormal PCWP, SWI, and MCSR died, and all of those who had normal values in all of these parameters survived.

Finally, left ventricular wall stiffness was assessed in terms of the relationship between left ventricular end-diastolic volume (LVEDV) and left ventricular filling pressure (LVFP, represented by left atrial mean pressure) (Fig. 5).

Among the patients whose LVEDV and LVFP were not increased, none died during the follow-up period. One out of 6 patients who had increased LVEDV with normal LVFP died. On the other hand, 3 out of 4 patients who had increased LVFP and not increased LVEDV died.

**DISCUSSION**

Sonnenblick and his associates have presented that maximal shortening velocity of the contractile element (max Vce) is an ideal index to represent myocardial contractility because the index is logically free from the effects of preload and afterload.\(^\text{14}\) However, maxVce has been proved to be not necessarily free from the effects of the preload,\(^\text{15}\) and the calculation of maxVce is not valid when applied to the ischemic heart with possible asynergistic contraction and variable compliance.\(^\text{16}\) On the other hand, Ross and his associate\(^\text{17}\) discussed that preload and afterload might be maintained relatively constant, especially in compensated heart with chronic cardiac overloading, and mean circumferential shortening velocity (Vcf) would provide the reliable measure of basal contractility in the individual patients. The situations are same for dp/dt, and dp/dt has been shown to be one of the best prognostic indices of acute myocardial infarction.\(^\text{16}\)

Stroke work index represents the total capacity of the heart as a pump and was proved to be useful in exploring the pump failure of acute myocardial infarction.\(^\text{1}\)

For these reasons, the left ventricular function was evaluated with dp/dt, LVSWI, and MCSR in the present study, and left ventricular contractile state was revealed to be significantly lower in Group I compared to Group II. The finding suggest that there are more advanced coronary circulatory disturbances in the patients with infarction than angina patients without infarction.

However, no significant differences were detected in CBF, Pcco₂, or MOEC of Group I and Group II. The validity of the method to estimate the coronary circulatory disturbances was discussed by one of us elsewhere.\(^\text{18}\)
The coronary blood flow of primarily left ventricular muscle is measured with \( \text{N}_2\text{O} \) method, and abnormalities of the distribution of the flow can not be detected with this method.

On the other hand, the most important differential point of myocardial infarction and angina without infarction is the presence of myocardial degeneration in the former.\(^{18}\) The presence of the massive myocardial degeneration means the loss of contractile elements, and thus the decrease of ventricular contractile state. Moreover, the myocardial degeneration is frequently associated with asynergistic ventricular movement,\(^{19}\) and occasionally with mitral valvular dysfunction.\(^{20}\)

All of these factors contribute to the decrease in left ventricular function with myocardial infarction. In our data, there are some overlaps of the data between infarction and angina groups. Some of the patients without preceding myocardial infarction show advanced myocardial degeneration and heart failure secondary to long-standing myocardial ischemia.\(^{5}\) On the other hand, a very localized myocardial infarction can go without significant ventricular dysfunction.

As already have been shown by other investigators,\(^{21}\) PCWP is clinically satisfactory index to estimate the left ventricular function, and RAP is misleading. In the present study, RAP was not significant to separate out 3 different groups of the patients, probably because the backward effects of the left ventricular dysfunction are damped by the pulmonary vascular bed and the right ventricle. The average values of PCWP were significantly elevated when the studies were performed within 24 hours of the attacks and 3 years after the attacks, and stayed within normal limits inbetween periods.

Rahimtoola et al.\(^{22}\) studied the left ventricular performance of 22 patients early (within the first 2 days) after acute myocardial infarction and again during the convalescent phase (3–5 weeks later). Left ventricular function had improved in 55% of the patients and had deteriorated in 18% during the convalescent phase. The latter group of patients had larger infarcts as compared with the former. Fluck and coworkers\(^{23}\) recorded serial measurements of pulmonary artery systolic pressure in 22 episodes of acute infarction during the initial 6 days. In 6 surviving patients pulmonary artery systolic pressure returned to normal at the end of the 6th day.

The time course of typical 2 cases were illustrated in Fig. 6. In one of the cases (F.S.), the marked elevation of PCWP was successfully treated with vigorous medical treatments and PCWP returned to normal 2 months following the initial attack. Another patient also showed elevated PCWP initially, and did not respond to therapeutic interventions and died in the state of cardiogenic shock 1 week following the attack.
Fig. 6 illustrates that the left ventricular function is deteriorated during acute period and changes to normal during the period of 3 months to 3 years after the attack, probably due to the therapeutic interventions and/or healing process of the infarction and partly due to dropping off with death. During the course of several years follow-up, myocardial degeneration will gradually progress to precipitate left ventricular failure.

Swan and his associates\(^1\),\(^{16}\),\(^{24}\) have presented that SWI, dp/dt, and compliance of the heart are excellent prognostic indices for the patients with acute myocardial infarction. In the present study, the combination of SWI, PCWP, and dp/dt (work, pressure, and contractility) was the best prognostic parameter for the patients with various stages of myocardial infarction.

The estimation of the compliance or stiffness of the heart is of great importance, but there has been no definite single index to represent the compliance of the heart in clinical cases.\(^{24}\)–\(^{26}\) The relation between left ventricular end-diastolic volume (LVEDV) and left ventricular filling pressure (LVFP, left atrial mean pressure was used in this study) allows semiquantitative evaluation of LV compliance. In this study, however, the patients with decreased LV compliance (elevation of LVFP without increase in LVEDV) showed poor prognosis.

In summary then, our data show that the advancement of coronary obstructive disease, especially of myocardial infarction, is accompanied with decreased contractility due to decreased contractile element, and increased
stiffness due to increased non-contractile element of the cardiac muscle, and the combination of these factors contributes to decide the ventricular function and prognosis.

REFERENCES