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Myocardial Metabolism in Coronary Insufficiency in Reference to Myocardial Oxygen Tension

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The oxygen tension of the myocardium was measured in the experimental coronary insufficiency by the polarographic method. The ST deviation of the epicardial ECG in coronary insufficiency was compared with the myocardial oxygen tension. The myocardium following the coronary occlusion was classified according to Sayen, namely the normal, border and central areas. Some metabolism of each area was studied.

CORONARY INSUFFICIENCY is caused by the unbalance between the oxygen supply to the myocardium and the myocardial demand for oxygen. The determination of the myocardial oxygen tension may be one of the most important studies to clarify the physiopathology of coronary insufficiency. Because the oxygen tension of the myocardial tissue is determined by the difference between the blood flow and the oxygen consumption of the tissue, the measurement of the coronary blood flow which has been used by many authors is merely the indirect method for the study of the oxygen tension. The polarographic method has been used for several years by the authors to determine oxygen tension of peripheral and cerebral circulation and it has been applied to the determination of myocardial oxygen tension. The myocardial oxygen tension in coronary insufficiency produced by experimental coronary narrowing or occlusion or by shock due to hemorrhage will be reported in this paper.

In 1950, Sayen et al¹⁾ reported first the measurements of oxygen availability of the myocardium. Only few except our previous studies²⁾ have been published in Japan. The

author will report the prolonged continuous polarographic records of the oxygen changes in coronary insufficiency and the correlation between myocardial oxygen tension and the epicardial electrocardiographic changes, especially the ST deviations. The ischemic muscles were divided into the central, border and normal areas following in Sayen. The differences of metabolism among these three areas will be described later.

METHOD

Healthy dogs weighing 9-25 kgms. were anesthetized by the intravenous injection of Nembutal on an average of 25 to 30 mg per kg. of the body weight. An incision was made on the left fourth or fifth intercostal space. The third and fourth ribs were removed. The pericardium was opened and sutured with the chest wall to support the heart. The respiration was maintained artificially by an electric pump respirator. One or two branches of the anterior descending coronary artery were freed from the accompanying veins and silk ligatures were placed around the branches for traction. The figure 1 will show the modification of the circuit of the polarographic apparatus. The open tip platinum electrode was used in this study. The electrodes

Fig. 1.

MYOCARDIAL EPG

Fig. 2.

were inserted mostly through the pericardium 2-6 mm into the myocardium. The direct electrocardiographic leads from the epicardial surface were made by the use of saline soaked cotton-tipped electrodes.

RESULTS**(1) Myocardial oxygen tension determined by polarographic method**

The values of the polarographic oxygen tension using the platinum electrode were fairly stable in the non-ischemic ventricular myocardium. (Fig. 2) The polarographic recording was sensitive to the fluctuation of the systemic blood pressure. Sometimes the record showed the fluctuation corresponding with the tertiary phase of the blood pressure. (Fig. 3) An inhalation of 100% oxygen induced an increase of the values by 50-200% within 30 seconds. Suffocation caused the prompt return to the original value. (Fig. 4)

Myocardial EPG **Systemic blood pressure**

Fig. 3.

MYOCARDIAL EPG

Fig. 4.

Dog No. 85 ♂
11.5 Kg

According to these results, it can be thought that the polarographic recording is a fairly precise method to determine the myocardial oxygen tension.

(i) The polarographic oxygen changes due to coronary occlusion.

After the occlusion of the distal portion of the left anterior descending coronary artery, the polarographic records of the is-

chemic areas changed rapidly to the zero level in about one minute. No influence upon the recording was seen by the pure oxygen inhalation or the intravenous injection of nor-epinephrine. They are called "central areas". The muscles being remote from the ischemic areas were not affected. ("normal areas".) In the areas between the central and the normal areas, which was called "border areas", the polarographic oxygen values decreased somewhat by the coronary occlusion and increased by oxygen inhalation to some extent. The results agree very well with those of Sayen et al.

However the author observed continuously the changes of polarographic recording for a long time, and found that the polarographic curve of the central area, where the curve fell nearly to the base line after the coronary occlusion, often began to rise slowly in a few minute, reached the top in 20 to

40 minutes and returned to the initial level within 80 to 90 minutes. (Fig. 5) The mechanism of this temporary rise of the curve is not fully understood yet.

The polarographic recording of the central area did not change by an oxygen inhalation and an intravenous injection of nor-epinephrine within two hours after the coronary occlusion. On the other hand, the curve rose slightly and gradually by the same procedure since three hours. (Fig. 6)

Myocardial EPG following Coronary Occlusion

Dog No. 71 ♂ 8.5 kg

Fig. 5 A.

myocardial EPG following Coronary Occlusion

Dog No. 71 ♂ 8.5 kg

60 Min

Fig. 5 B.

Dog No. 71 ♂ 8.5 kg

O₂ Inhal.
+
NorEpi. 20 ♂

95 Min

O₂ Inhal.
+
NorEpi. 20 ♂

131 Min

O₂ Inhal.
+
NorEpi. 20 ♂

177 Min

Fig. 6 A.

4 H.

5 1/2 H.

7 H.

8 H.

Fig. 6 B.

The fact seems to indicate that the coronary collateral circulation has become active by this time.

(ii) Polarographic oxygen changes after coronary narrowing.

Acute coronary narrowing had similar effects to the occlusion but the fall of the polarographic curves was more variable in proportion to the extent of the narrowing.

(iii) Polarographic oxygen changes after

Fig. 7 A.

7. Fig. 7 B.

hemorrhagic shock.

When the systemic blood pressure dropped to 40 to 50 mm Hg due to experimental bleeding, polarographic oxygen tension decreased in accordance with the fall of the blood pressure. (Fig. 7) The cause may be due to the depression of blood pressure and the insufficient coronary blood flow. The polarographic changes after hemorrhagic shock differed from those in coronary occlusion and narrowing. An inhalation of pure oxygen caused rapid rise of the curve in hemorrhagic shock.

The behavior of the myocardium towards the oxygen inhalation was compared between the outer layer and the inner layer. The records of the latter layer were

Dog No. 65 ♂
20.5

Fig. 8.

fairly inconstant and unstable and the reaction to the inhalation of oxygen was much less. (Fig. 8) Further studies should be done before the conclusions that the both layers are different substantially are drawn.

(2) Correlation between myocardial oxygen

tension and epicardial electrocardiogram, especially the ST deviation. In the case of narrowing, the fluctuation of ST elevation was seen in accordance with the polarographic fluctuation of the oxygen ten-

Fig. 9.

tension and epicardial electrocardiogram, especially the ST deviation.

In coronary occlusion, the polarographic oxygen values began to fall in a few seconds, but no changes were seen in epicardial ECG until the values of polarographic oxygen reached 60% of the initial value. (Fig. 9) The elevation of ST segment appeared in

sion. It was interesting that the slight increase of the polarographic oxygen tension caused the decrease of ST elevation, even when the polarographic oxygen tension was still in the fairly low level. (Fig. 10) The negative correlation between the values of polarographic oxygen and the elevation of ST segment was seen when the values were under 60% of the initial value in the case of the occlusion (Fig. 11) and under 30 to 40% in the case of narrowing. (Fig. 12)

Correlation between EPG and ECG

during Coronary Narrowing

Fig. 10.

Correlation between EPG and ST Elevation

Fig. 11.

Fig. 12.

These data may indicate that the myocardial oxygen tension is not the primary factor in the elevation of ST segment but some metabolic changes due to the oxygen deficiency are more potent factor. But the potassium concentration of coronary sinus blood did not increase either in thirty seconds or in one minute after the occlusion. Further works should be done to decide whether ST elevation is caused by the increase of the serum potassium concentration.

In hemorrhagic shock, ST depression appeared after the myocardial oxygen tension fell to the fairly lower level. The correlation between ST depression and the polarographic oxygen values was seen when the values were under 40 to 50% of the initial. (Fig. 13) Moreover, the potassium concentra-

Fig. 13.

tion of the peripheral venous blood was not associated with the ST depression in this case.

(3) Myocardial metabolism in the coronary occlusion

(i) Glycogen: In ischemia, the demands for energy were met mostly by glycolysis. It is natural that the myocardial glycogen decreased with the lapse of time. The authors measured separately the acid-soluble fraction and the non-acid-soluble fraction of cardiac glycogen. The value of the acid-soluble fraction was fairly constant and mainly the acid-soluble fraction decreased after the coronary occlusion. But the accumulation of the myocardial glycogen was not seen in the border area.

(ii) Catecholamine: Myocardial catecholamine of the central area tended to decrease 2 weeks after the coronary occlusion but that of the border area did not always increase.

(iii) Myocardial electrolytes and histologic examinations: Plasma sodium and chloride tended to decrease and potassium increased slightly till several hours after the occlusion, but after that no definite tendency was seen.

Sodium, chloride and water contents of the myocardium increased gradually in the central area and especially they increased markedly 24 hours after. On the other hand, myocardial potassium decreased 1 hour after and the decrease was marked 24 hours after. Potassium content of the border area was between that of the central area and of the normal area.

No microscopic changes were seen until 3 hours after the occlusion. But the slight changes such as homogenization of sarcoplasm and acidophilic degeneration were seen 6 hours after. In electron microscopic findings, no changes were seen 30 minutes after and the slight changes such as fragmentation and swelling of myofibrils, dilatation of reticulum and swelling of mitochondria, were found 3 hours after. But no definite relationship was seen between the histologic findings and the myocardial potassium and water content or the polarographic oxygen tension.

DISCUSSION

The physiological classification of the

myocardial areas by polarographic method was first reported by Sayen et al.¹⁾

Many observations which had been made by Sayen were carried out only for short periods after coronary occlusion or narrowing. The polarographic readings by Sayen were at one minute intervals, but we tried to get a long continuous recording of myocardial oxygen tension. One of the most striking findings reported here is the fairly constant transient increase of the polarographic oxygen tension following the sharp fall after the coronary occlusion. This phenomenon may be based on the opening of preexisting non-functioning collateral circulation due to the change of the pressure difference or to the effect of some unknown metabolites produced by the lack of oxygen following the coronary occlusion. On the other hand, the decrease of the oxygen consumption in that area may also be related to the phenomenon. But the details of the mechanism are still unknown. Polarographic oxygen tension of the central area increased owing to the pure oxygen inhalation together with the injection of nor-epinephrine from 3 hours onward after the occlusion. This fact may indicate that the activity of the collateral circulation begins much earlier than ever reported.

It has been known that the deeper layer of the myocardium is much less resistant to coronary insufficiency. The polarographic oxygen tension of the deeper layer (more than 10 mm in depth) was labile and the rise due to the oxygen inhalation was much less than that in the superficial layer. Many difficulties lie in concluding that the deeper layers are different from the superficial ones. In this problem, our study is in progress.

Sayen et al.³⁾ reported that the polarographic fall of the oxygen tension was more sensitive than the epicardial ECG changes in coronary occlusion. According to our

results, the ST elevation appeared at 20 to 30 seconds after the coronary occlusion when the polarographic oxygen tension had fallen about 60% of the initial level. The close relationship was seen only under 60% of the initial value in the case of the coronary occlusion and under 30 to 40% in the case of the narrowing. The fact may suggest that the myocardium has the threshold for the elevation of ST and the oxygen deficiency is not the primary factor for the elevation of ST. Some unknown metabolites produced secondly by the lack of oxygen has been supposed to be more responsible for the ST elevation. But the serum potassium measured by coronary sinus catheterization or that of the peripheral venous blood did not change even in the ST deviations.

SUMMARY

The polarographic oxygen tension of the myocardium was studied in the experimental coronary insufficiency. The author revealed the course of the formation of collateral circulation in the coronary occlusion. Electrocardiographic ST deviation in coronary insufficiency was not primarily related to the myocardial oxygen tension but to some metabolites produced by anoxia. As to the central, border and normal areas in coronary occlusion, some metabolism was studied to decide whether the border area showed a specific reaction.

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