FATTY ACID METABOLISM DURING EXTRACORPOREAL CIRCULATION IN MAN

KEIICHIRO KATSUMOTO

There are three main methods utilized in the study of the myocardial metabolism, they are 1) the method with coronary catheterization\(^1\), 2) the method using isolated perfused heart\(^2-8\), 3) the method using incubation of the sliced heart tissue. During open-heart surgery using cardiopulmonary bypass, blood samples can easily be obtained from coronary sinus, so that from the arterio-venous difference one can study the myocardial metabolism during perfusion, and the metabolism of the arrested heart and also the metabolism of the resuscitated heart.

In the case of a radical operation for the tetralogy of Fallot, the fresh myocardium of the stenotic infundibulum in the right ventricle can also be obtained.

The author has studied the levels of glucose, fatty acids, and lactate in the blood during cardiopulmonary bypass of 34 patients being treated for various types of heart disease. The author has also extracted the lipids from the freshly resected myocardium in the operative cases of the tetralogy of Fallot and has studied muscle phospholipids which are separated by a thin-layer chromatography and which are analysed by a gas chromatography.

The author intended to clarify the metabolic changes before and after anoxic arrest or the induced fibrillation of the human heart, especially from the standpoint of lipid metabolism.

**METHODS**

The author has analysed glucose, lactate and free fatty acids (FFA) of the blood of artery and coronary sinus in the case of various heart diseases during cardiopulmonary bypass. The heart diseases concerned are classified in Table I: ventricular septal defect 13, atrial septal defect 9, the tetralogy of Fallot 7, aortic valvular stenosis 2, mitral insufficiency 2, aortic insufficiency 1.

The perfusion apparatus consisted of a rotating disc oxygenator or disposable sheet oxygenator with standard roller pumps.

The oxygenator was primed with fresh heparinized whole blood hemodiluted with low molecular-weight dextran solution or with ACD-heparinized blood with 15 to 40 per cent hemodilution using lactated Ringer's solution and perfusions of 50 to 120 ml/kg/min at temperatures of either 31 or 37\(^\circ\)C were utilized in all cases. Samples were taken from the right atrium within 3 minutes after the start of total cardiopulmonary bypass, however, in the case of ASD, blood samples were obtained directly from coronary sinus after incision of right atrium. The root of the aorta in 29 cases was occluded intermittently for 15-minute periods to produce ischemic arrest and two minutes intervals were set for coronary perfusion with the release of aortic occlusion. The total aortic...
TABLE I  THE HEART DISEASE CONCERNED

<table>
<thead>
<tr>
<th>Patients</th>
<th>VSD</th>
<th>ASD</th>
<th>Fallot</th>
<th>AS</th>
<th>MI</th>
<th>AI</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normothermia</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Hypothermia</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>total</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>34</td>
</tr>
</tbody>
</table>

Oclusion time ranged from 40 to 100 minutes. Induced ventricular fibrillation was used in the 5 cases of valve operation.

Blood samples from coronary sinus and oxygenator were simultaneously obtained just 40 seconds after the last clamping of the root of the aorta and 10 minutes after the final clamping. The author studied the arterio-venous differences in the hearts.

Blood glucose, lactate and free fatty acids (FFA) and myocardial lipid extractions were performed as follows:

- Blood glucose: orthotoluidin method (simultaneous determination of dextran and glucose in serum)
- Blood lactate: enzymatic analysis $^6$ (R. Scholz)
- Free fatty acids (FFA): cobaltnitrosoprophol complex method of Milan Novak $^5$
- Separation of FFA from plasma: Lars Hagenfeldt's method $^9$
- FFA standard: palmitate (Sigma Chem. Co Grade 99%)
- Methylation of fatty acids: methanol-dimethoxy-propane method (Haruo Nakamura)
- Spectrophotometer: Shimazu Spectronic 20
- Gas chromatography: Hitachi KGL-2B FID-2 Flame Ionization Detector, succinate polyester 15% / celite 60 to 80mesh, column length 2000 mm, column temperature 250°C, oven temperature 300°C, flow rate of carrier gas (N2: 0.5 kg/cm air: 1.2 kg/cm, H2: 0.7 kg/cm)
- Lipid extraction from myocardium: Folch's method $^9$, with ice-cold chloroform-methanol solution using the 12,000 RPM homogenizer.
- Separation of phospholipid: thin-layer chromatography using 250 micron silicagel plate, $20 \times 20$ cm, produced by Tokyo Kasei Co., Ltd.

Phospholipids were separated on thin-layer silicic acid plates, using the solvent system of hexaneethylthlylether-acetic acid (234: 60:10 V/V)

Methylation of phospholipids: same as above, the methylated phospholipids were analysed by gas chromatography.

**RESULTS**

1) Energy balance of the human heart

As an energy source the human heart depends on glycogen, fatty acids and lactate in the myocardium and extracts glucose, fatty acids and lactate from the blood and can transfer them to contraction energy.

The heart extracts these substrates and holds an energy balance. The energy balance alters at infusion of glucose and at the time of insulin, glucagon and epinephrine injection.

The author has studied the arterio-venous differences, in the heart, of glucose and free fatty acids to assess the energy balance of the human heart immediately after the start of total cardiopulmonary bypass.

The myocardial uptake or excretion of free

![Fig. 1. A-V differences in the heart of glucose and free fatty acids (FFA) to assess the energy balance of the human heart immediately after the start of total cardiopulmonary bypass.](image)

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fatty acids (FFA) is shown in the X-axis and that of glucose on Y-axis in Fig. 1.

Within preferable values the heart extracts FFA and glucose. When FFA is highly extract-
ed, the heart cannot extract glucose. And when there is an excretion of FFA from the myocardium, glucose can not be extracted.

2) Lactate

There is a tendency for lactate to gradually accumulate during the period of general anesthesia.

Especially during the perfusion of extracorpo-
real circulation, as the blood pressure re-
main remains low (40 to 80 mm/Hg) and peripheral tissue circulation is disturbed, so the blood lactate increases gradually. The increase of lactate in the perfusate of the normothermia and at the hypothermia (31°C) was compared. As is indicated in Fig. 2, there was a more prominent increase of lactate in normothermia. Therefore, there would be no disadvantage in normothermic perfusion up to 30 minutes but beyond that time moderate hypothermic per-
fusion would be desirable.

The author has found the suppressive effect of lactate accumulation at normothermia with the pharmacological premedication of anti-
thyroids such as Endojodin and methisil (methylthiouracil), as is indicated in Fig. 2 below. Endojodin 30 mg/kg or methisil 6 mg/kg was injected per cutaneously or intramuscu-
larly or per parenterally, at intervals of 12 hrs. and 3 hrs. before the operation. This anti-
thyroid premedication would also be useful for the treatment of abnormal metabolic in crease during post-operative fever.

When the perfusate's lactate values were compared in the tetralogy of Fallot between 40 seconds after the last declamp of occlusion of the ascending aorta and 10 minutes there-
after, there were marked increases of lactate at 10 minutes after the last declamp.

This increased rates of lactate accumulation may be the peripheral tissue lactate, released as the temperature increases by rapid re-
arming. (Fig. 3)

3) Alteration in blood FFA during extracorpo-
real circulation

As in Fig. 4, the concentration of FFA in the perfusates 2 or 3 minutes after the start of total perfusion, were 100% and the altera-
tion were indicated periodically. Decrease in circulating FFA may be attributed to the ester-
ification of FFA due to the hyperglycemia.

Blood glucose concentration were increased four to six times during the perfusions mainly because of substantial addition of low molecu-
lar-weight dextran and glucose to the priming solution.

On the other hand, under the neurolept-
anesthesia, because the oxygenator was no remarkable hyperglycemia. In such cases there was a tendency of FFA increase.

There were no differences of FFA concentra-
tion alteration between normothermia and hypothermia (31°C).

4) The coronary arterio-venous difference of FFA

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*Figure 2*: (above) The increase of lactate in the perfusate of the normothermia and at the hypothermia (31°C) was compared. (below) The suppressive effect of lactate accumulation at normothermia with the pharmacological premedica-
tion of antithyroids.
Fig. 3. The perfusate's lactate concentrations were compared in the 9 cases of tetralogy of Fallot between 40 sec. after the last release of occlusion of the root of the aorta and 10 minutes thereafter. There were marked increases of lactate at 10 minutes after the last declamp.

Fig. 4. The concentration of FFA in the perfusates. The alterations were indicated periodically. The concentration of FFA in the perfusates 2 to 3 minutes after the start of total perfusion were estimated at 100%. (----- indicates cases of normoglycemia, as the oxygenator was primed with lactated Ringer's solution.)

FFA is extracted by the normal human heart according to the studies obtained by the coronary sinus catheterization technique. The coronary A-V difference of FFA during the period of total perfusion was studied as samples were taken at 2 to 3 minutes after the
TABLE II  MYOCARDIAL EXTRACTION & EXCRETION OF FFA DURING EXTRACORPOREAL CIRCULATION

<table>
<thead>
<tr>
<th></th>
<th>control (3 min. after the start of perfusion)</th>
<th>40 sec. after the release of the occlusion of the aorta</th>
<th>10 min. after the release of the occlusion of the aorta</th>
</tr>
</thead>
<tbody>
<tr>
<td>extraction</td>
<td>16(64%)</td>
<td>10(45.4%)</td>
<td>10(90.4%)</td>
</tr>
<tr>
<td>excretion</td>
<td>7(28%)</td>
<td>10(45.4%)</td>
<td>1(4.8%)</td>
</tr>
<tr>
<td>no A-V difference</td>
<td>2(8%)</td>
<td>2(9.2%)</td>
<td>1(4.8%)</td>
</tr>
<tr>
<td>total</td>
<td>25</td>
<td>22</td>
<td>21</td>
</tr>
</tbody>
</table>

TABLE III  MYOCARDIAL EXTRACTION & EXCRETION & EXCRETION OF FFA DURING INDUCED VENTRICULAR FIBRILLATION

<table>
<thead>
<tr>
<th></th>
<th>3 min. after the start of perfusion</th>
<th>during induced fibrillation</th>
<th>40 sec. after defibrillation</th>
<th>10 min. after defibrillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>extraction</td>
<td>3</td>
<td>3</td>
<td>____</td>
<td>4</td>
</tr>
<tr>
<td>excretion</td>
<td>2</td>
<td>1</td>
<td>____</td>
<td>3</td>
</tr>
<tr>
<td>no A-V difference</td>
<td>____</td>
<td>____</td>
<td>____</td>
<td>____</td>
</tr>
</tbody>
</table>

start of perfusion (before the occlusion of the root of the aorta) and 40 seconds immediately after the last declamp of the aorta and at 10 minutes after the final declamp. The results are indicated in Table II. In this table, the values of A-V difference more than 5 per cent of arterial values were decided to be the extraction by the myocardium. From the A-V difference at the time when the total perfusions started, FFA were extracted by myocardium in 64% of the cases. Immediately after the declamp of the root of the aorta, the number of cases of extraction and excretion were the same. At 10 minutes after the declamp of the aorta, FFA extraction was noted in almost every case.

5) A-V difference of FFA during the induced ventricular fibrillation

During the induced ventricular fibrillation (15 to 30 minutes after the start of fibrillation) the myocardium extracts FFA, on the other hand about 40 seconds after defibrillation, FFA are released from the myocardium. But at 10 minutes after defibrillation, the heart extracts again FFA. (Table III)

6) Alteration in percentage composition of the arterial FFA during perfusion

The composition of the FFA in perfusate from 10 cases is shown in Fig. 5. Percentage of palmitate increases with perfusion time. Oleate decreases but stearate remains unchang. It is of great interest that linoleate always ed. decreases with perfusion time. Lipotate LE10 (methyl-linoleate with pyridoxin and tocopherol) were given to two patients orally from 3 days before the operation (0.4 ml/kg/day), and 24 hours before operation antithyroids were given. The alteration in FFA composition in these premedicated patients remained constant. The data from these two patients is shown by the dotted line in Fig. 5.

7) Alteration in percentage composition of the arterio-venous FFA difference

As indicated in Fig. 6 a few minutes after the start of perfusion, the heart of almost every case extracted FFA. Palmitate and oleate was mainly extracted. Forty seconds after the last declamp of the ascending aorta, the heart was resuscitated and began beating. From the study of arterio-venous difference at this time the metabolism of the heart in anoxic or hypoxic state was estimated. Immediately after the release of anoxic occlusion, palmitate was never extracted by the myocardium, however, oleate and linoleate were mainly extracted. Ten minutes thereafter, FFA was easily ex-
tracted, mainly palmitate and oleate. This showed a metabolic recovery of the heart from anoxia. But linoleate, because of the lack of quantity at the end of the perfusion time, showed no remarkable A-V difference. (Fig. 6)

8) Alteration in percentage composition of phospholipids from anoxic myocardium

Phospholipids play a great role in the brain and heart as a structural lipid. Fatty acid composition of phospholipids is mainly arachidonate and linoleate, both contain double bond. From the study of the isolated heart, perfused with a medium which contains C14l-palmitate, the incorporation of palmitate into myocardium and subsequent constitution of neutral lipid and phospholipid was found.

In this report, heart muscles from right ventricular infundibulum were obtained in the radical operation of tetralogy of Fallot, which was immediately homogenized with an ice-cold Folch solution (chloroform: methanol 2: 1) in a metal conical homogenizer. According to the Folch's method, lipids are concentrated. Using thin-layer chromatography the concentrated lipids were separated and phospholipids were obtained. Fatty acids were methylated and were analysed by a gaschromatography. The results are shown in Fig. 7. The percentage compositions are compared according to the time when the heart muscles were resected in the operation. The values on the left of the charts show the percentage of fatty acids from the heart muscle which were resected immediately after the first occlusion of ascending aorta, the values on the right show those muscles which were resected just before the suture of the wall of the right ventricle, namely about 60 to 70 minutes after the cardiopulmonary bypass. According to Fig. 7, the percentage of palmitate increased after 60 to 70 minutes. This fact resembles the data obtained in the alteration of palmitate in arterial blood during extracorporeal circulation. On the other hand, the percentage of the unsaturated fatty acids, for example, linoleate and arachidonate decreased as perfusion time prolonged. This is, the author thinks, due to the hypoxic response of cardiac muscle cells during extracorporeal circulation.

Discussion

It is nowadays an inevitable procedure for open-heart surgery under cardiopulmonary bypass to use the technic of aortic occlusion or that of induced ventricular fibrillation with or without coronary perfusion.

The heart resuscitates itself even after 30 minutes occlusion of the root of the aorta. In our previous reports10-11, from the standpoint of lactate values from arterio-venous differences in the heart, the method of 15-minutes periods of intermittent occlusion of the root of the aorta with two minutes of coronary perfusion between those periods of occlusion resulted in good myocardial recovery.

However, after the operation, even though the heart beats were in good recovery, there

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were some cases which showed low cardiac output syndrome and metabolic acidosis, which was sometimes fatal. In this case the operative procedure and technical problems and the effects due to the long term perfusion must be considered first but also the effects of operation on myocardial metabolism must be considered.

Thus myocardial metabolism during the extracorporeal circulation is also important, especially in long periods of extracorporeal circulation.

At any rate, after start of cardiopulmonary bypass, the metabolic state should be in a good condition. In fasting conditions, the mean oxidation extraction ratios are FFA: 60%, glucose: 28%, and lactate: 11%, and the respiratory quotient approaches 0.713.

Therefore, as is shown in Fig. 1, at the time when the perfusion pump started, the myocardium showed an energy balance between FFA and glucose. It was not in a good energy balance state when the heart was extracting too high values of FFA alone. Usually FFA concentration of normal human arterial blood decreases if glucose is injected intravenously. Because of the substantial addition of glucose and low molecular-weight dextran to the priming solution, FFA concentration in arterial blood decreased. On the other hand, FFA concentration in arterial blood increased in those cases in which lactated Ringer's solution with ACD-heparinized blood were used as a perfusate. What kind of mechanism is the alteration of FFA in the arterial blood during perfusion?

According to the basic study, injection of noradrenalin, adrenalin or isoproterenol makes FFA concentration in blood higher in vivo, however, the injection of glucose makes FFA concentration lower, and at the same time, glycerol is decreased. Form this fact, glucose has a role in the FFA esterification mechanism13.

Adrenalin and other amines have another action in the release of FFA directly from fat tissues in vitro. On this point, the author studied. As in figure 8, two grams of canine

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subcutaneous fat tissues are sliced in 50 ml saline, and to this mixture 1 ml of epinephrine 1/1,000 solution is added and incubated at 37°C. The release of FFA is remarkable after 30 minutes incubation. Bray has also studied this fact. Bray, moreover, reported that the β-blocking agents suppressed the release of FFA but the α-blocker didn’t suppress FFA release at all. There is also the same study about human response of epinephrine in vivo.

For the purpose of lessening vasoconstriction during extracorporeal circulation, it is reasonable to use α-blocking agents. Since 1965, neurolept analgesia has been used for anesthesia of open-heart surgery. For the anesthesia of the three cases of tetralogy of Fallot, opystan (or fentanyl) and droperidol was used. In those cases, lactated Ringer’s solution was used as a prime, and that attributed to the FFA increment during the perfusion. Droperidol has the α-blocking activity.
and FFA release was not disturbed. In greater part of cases in this report, hyperglycemic perfusion was used, so that the decrease of FFA as perfusion time prolongs was noted.

One reason may be the esterification of FFA and another reason may be the extraction of FFA in coronary blood by the myocardium as an energy source. In five cases of the induced fibrillating hearts, FFA was usually extracted, however, just after defibrillation the arteriovenous difference was reversed. Ten minutes after defibrillation, FFA was again extracted by the myocardium. This alteration in blood FFA resembles the pattern of lactate which was reported by Nosawa.11

Hyperglycemic perfusion is useful for ventricular function such as contractile force after defibrillation19. As is mentioned above, blood catecholamine level increases during extracorporeal circulation.19

There are a few reports, in medical literature about fatty acid alteration during extracorporeal circulation. M. Jellinek20 has reported alteration in blood lipids during extracorporeal circulation in man. According to his report, the increases of FFA is noted after 15 minutes from the start of perfusion, and thereafter no remakable change is noted. On the other hand, he noted a somewhat decrease of total plasma fatty acid. There are no reports about alteration of fatty acid constitution in human myocardium during extracorporeal circulation. From basic studies there are a few reports using C14-palmitate in the isolated perfused canine or rat heart.5-6 Olson2 demonstrated that the C14-palmitate incorporated into heart lipids was evenly distributed between neutral lipids and phospholipids.

J. Scheur4 demonstrated that, during ischemic state of coronary perfusion in the dog heart, the fractional distribution of extracted palmitate-C14 showed a significant shift with a decrease of label in tissues FFA and an increase in the triglyceride fraction. He also demonstrated that lipoprotein lipase activity in heart muscle was markedly suppressed during ischemic perfusion. In this author's report, after release of occlusion of the root of the aorta, the palmitate was released from the myocardium and no extraction of palmitate was noted. But oleate and linoleate were extracted in some cases. Is there any method for the prevention of the decreases of linoleate in the perfusate or of the decrease of linoleate and arachidonate in the heart muscle phospholipid?

First, the suppression of fatty acid metabolism is considered. The hypothyroidism subjects response to the epinephrine action of FFA release in the blood was less than the normal subjects. On the other hand, the subjects of hyperthyroidism responded to FFA release prominently after the epinephrine injection.21

From these facts, the author decided to use antithyroid, such as endojodin and methyosil (methyl thiouracil) preoperatively. The second idea is the preoperative dosage of fatty acid, especially those which contain double bonds. For these purpose, Lipotate LE 10 (methyl linoleate with antioxidant, pyridoxin) was selected for the preoperative dose. According to the basic study of Scheier,22 simultaneous dosage of linoleate and pyridoxin for three days causes an increase in linoleate percentage in rat heart lipids. And so this drug was selected for dose three days before the operation. Schoen23 found that the preoperative medication in the form of endojodin and essential phospholipid and persantin injection, was useful in order to improve the energy supply during anaerobic metabolism, and he found that this premedication resulted in prolongation of the permissible time of circulatory standstill. Higasa24 (Kyoto University) has also used pharmacologic premedication in the form of methyl linolate and its antioxidant one week before the operation, for the purpose of preventing lung edema and ventricular fibrillation during profound hypothermia. Okamura25 has also specially devised the premedication cocktail which he calls the hibernation cocktail (pethilorfan and vesprin and atarax P) for the purpose of depression of catecholamin release in the blood and he rarely experienced ventricular fibrillation during profound simple hypothermia.

Phospholipids are essential constituents of mitochondria. In the prolonged anoxic state,
mitochondria of myocardium becomes swollen and cristae destruction occurs. The author supposes that the destruction of the mitochondrial membranes and cristae would be initiated from the structural phospholipid change, that is the alteration of polyunsaturated fatty acias (mainly linoleate and arachidonate), which is shown in Fig. 7. Phospholipid has a great role in the electron transfer system and oxidative phosphorylation in the mitochondria. Namely, phospholipid must be studied in the field of cardiovascular surgery.

There are not so many studies of percentage compositions of FFA in the arterio-venous difference of human heart. According to Carlsten and others, mean human FFA concentration in arterial blood is 636 μEq/L and in venous blood 501 μEq/L, so it is apparent that there are some positive arterio-venous differences namely the extraction by myocardium. According to their percentage compositions, both oleate and palmitate are extracted but there are some cases which show the reversed A-V differences of palmitate, moreover, they think that there would be a threshold value for FFA extraction by myocardium, that is 354 μEq/L.

From the author’s study, the idea of a threshold concentration for FFA is obvious. The results obtained by Carlsten, that And, steatate is extracted without any threshold value is also in question.

From the author’s study, the reversed A-V difference of palmitate occurs in almost every case 40 seconds after the release of the occlusion of the root of the aorta. This fact may be attributed to the effect of anoxia in the myocardium. In the tetralogy of Fallot, after surgical correction of VSD, the root of aorta is released for resuscitation. Five to ten minutes after this state, even though the aorta is again occluded, the blood in the left ventricle flows through the coronary circulation (in those cases, no insertion of LV vent) and the beating never stops, as if it is an isolated perfused heart lung preparation. Even in this extreme state, palmitate reverse is found in author’s results immediately after the release of the root of the aorta.

Oleate can be exclusively extracted at time immediately after the release of the aorta occlusion, so oleate is thought to be easily extracted during the hypoxic state.

Rothlin and Bing reported the FFA percentage compositions in coronary sinus blood, and showed that oleate was more easily extracted by myocardium than palmitate, which is consistent with the author’s result.

Conclusion

The author has studied the level of glucose, FFA, lactate in the blood of 34 patients (totals) being treated for various types of heart disease during extracorporeal circulation. For 18 patients, arterio-venous differences in the heart of glucose and free fatty acids (FFA) were studied to assess the energy balance of the human heart. The increase of lactate in the perfusate of normothermia and 10 cases at the hypothermia (31°C) was compared. Three cases were premedicated with antithyroids. The perfusate’s lactate concentrations were compared in the 7 cases of tetralogy of Fallot. For 28 cases the alterations of FFA in the perfusate were studied. For 25 cases, myocardial A-V differences of total FFA were studied before the occlusion of the root of aorta, 40 seconds after the release of it and 10 minutes thereafter were studied. For 5 cases, A-V differences of total FFA during induced ventricular fibrillation were studied. For 9 cases, the A-V differences of myocardial fractional FFA concentration before the occlusion of the root of the aorta, 40 seconds after the release of it and 10 minutes thereafter were studied. For 10 patients, the FFA percentage composition in the perfusate was studied. And 3 cases of tetralogy of Fallot, the heart muscle mass from the right ventricular infundibulum were resected at the time of aortic occlusion and also at about 60 minutes after intermittent arrests immediately before the suture of the incision of the right ventricular wall. The lipid were extracted from the heart muscle thus obtained, and phospholipids were separated and analysed for fatty acid percentage composition, and the alteration as to the duration of anoxic arrest was studied.

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The results obtained were:
1) glucose and FFA were extracted by myocardium as an energy source with balanced values of both.
2) Lactate concentrations in perfusate gradually increase but the rate of increment was less at hypothermic perfusion.
3) The suppressive effect of lactate accumulation at normothermia with the pharmacological premedication of antithyroids were obtained.
4) FFA in perfusate was usually decreased under hyperglycemic perfusion.
5) The alterations of the percentage composition of FFA in the perfusate were the increment of palmitate and decrease of oleate and linoleate.
6) Coronary arterio-venous difference of FFA at the time before anoxic occlusion of the ascending aorta was positive, that is to say, 64 per cent out of 25 cases extracted FFA. The composition of this FFA was mainly oleate and palmitite.
7) About 40 seconds after the release of the occlusion of the aorta, case numbers which showed positive and negative FFA differences were the same. The composition of these cases were mainly the release of palmitate and extraction of oleate or linoleate.
8) After 10 minutes from release of the aortic occlusion, FFA was extracted in almost every case. In these cases, palmitate and oleate were mainly extracted but it was impossible to extract linoleate because of the low concentration at nearly end of the perfusion.
9) There were almost the same results in fatty acid percentage composition of phospholipids from the heart muscles, namely, a decrease of linoleate and arachidonate was noted and the increase of palmitate percentage was remarkable.
10) A-V differences of FFA in cases of induced ventricular fibrillation, were that the myocardial extraction occurred during fibrillation and reversed A-V difference occurred immediately after defibrillation.

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