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Brain Circulation in the Acquired Heart Diseases

By

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(Received for Publication, June 6, 1956)

I. INTRODUCTION

It is well known that when the oxygen supply becomes insufficient in the brain, heart, liver and other organs, dangerous conditions such as shock are apt to arise. Especially in heart diseases since an insufficient oxygen supply occurs easily and reactions to such condition occurred in important organs are relatively great, the problem of the oxygen supply is considered very important. Inasmuch as the brain is most easily affected by anoxia, problems related to the brain circulation in cardiac surgery are extremely significant. We have made studies of the brain circulation in heart surgery from such standpoint, and today we will present here our studies related only to acquired heart diseases as the problem assigned to us.

II. THE CHARACTERISTICS OF THE BRAIN CIRCULATION IN ACQUIRED HEART DISEASES

Measurements by Scheinberg's method of the brain circulation in operation cases of acquired heart diseases indicate that the cerebral blood flow and the oxygen consumption of the brain decrease while the cerebral vascular resistance increases. (Fig. 1)

On the other hand, in congenital heart diseases, particularly in shunt and cyanosis the reverse situation is after found.

In experimental dogs in which conditions similar to various acquired heart diseases are produced artificially, tendencies similar to those found in clinical cases are recognized. Here the smaller the cardiac output, the smaller also is the cerebral blood flow. (Fig. 2) Since in diseases with stenosis, the

Fig. 2 The relation between the cardiac output and the cerebral blood flow in acquired heart diseases.

Case No.	Name	Sex	Age	Weight (kg)	Diagnosis	Cardiac output l/min.	O ₂ Consumption c.c./min.	Cerebral blood flow cc/min/100gr brain	Cerebral metabolic rate cc/min/100gr	Cerebral vascular resistance mmHg/100gr/min.
1	K. Y	♂	46	49	Mitralstenosis	2.69	240	38.6	2.0	2.4
2	K. U	♀	43	44	"	1.5	300	38.0	1.3	1.26
3	M. N	♂	30	54	"	3.24	300	35.0	1.23	2.8
4	H. M	♂	34	45	"	3.0	375	37.6	4.86	2.6
5	N. I	♂	23	54	"	4.3	305	24.8	0.38	4.3
6	T. I	♂	25	46.7	"	3.43	240	53.7	2.04	1.9
7	H. S	♂	24	51	"	4.7	250	30.8	1.6	3.4
8	H. T	♂	32	53	"	3.9	225	43.0	2.45	1.9
9	S. Y	♂	25	42.5	"	3.5	183	38.4	2.0	2.13
10	K. T	♂	16	32.8	Mitralstenosis + insufficiency	2.6	210	45.0	2.9	1.33
11	M. H	♂	21	50	Mitralstenosis + Aorticstenosis	1.68	185	26.25	1.71	3.7
12	Y. I	♂	30	54.3	"	4.69	218	42.2	1.37	2.13
13	H. K	♂	21	53	Constrictive pericarditis	2.1	240	32.5	2.7	2.4
14	G. Y	♂	20	54	"	3.2	87.5	55.5	1.5	1.5

Fig. 1 Brain circulation of acquired heart diseases. (N₂O method)

cardiac output is not reduced much, the reduction of the cerebral blood flow is not necessarily a consequence of the reduction of the cardiac output. It seems rather that the increase of the cerebral vascular resistance is an important factor, because the reduction of the cerebral blood flow is approximately in parallel with the increase of the cerebral vascular resistance. (Fig. 3) The brains in 13 cases

Fig. 3 The relation between the cerebral blood flow and cerebral vascular resistance in acquired heart diseases.

of acquired heart diseases showed in many cases fibrosis in the adventitia of the cerebral arteries. This change tends to be more conspicuous in the basal area. Consequently the increase in the cerebral vascular resistance seems to be due largely to the organic changes of the cerebral arteries. Since after operation the cerebral vascular resistance decreases and the cerebral blood flow increases, it is not always necessarily caused by the organic changes of the blood vessels; functional factors seems to exist also. It may be added here that in mitral stenosis constant relationship does not exist between the cerebral blood flow and the size of the valve opening or the age.

III. EFFECTS OF OPERATION ON THE CEREBRAL CIRCULATION IN ACQUIRED HEART DISEASES

Effects of operation on the cerebral circulation in acquired heart diseases will be considered next. Various methods are known for measurements of the cerebral blood flow. For the consideration of effects of operation, they are difficult to understand unless the delicate changes of the blood flow are accurately recorded with time. Machiyama of our department prepared an electro-blood-pressure manometer and an electromagnetic flow meter shown in the figure 2 which is an improvement

Fig. 4 Electromagnetic Flowmeter.

of a similar instrument made by Richardson.

These instruments record changes with time of the blood flow as well as the blood pressure in the form of curves. Intermediate values are recorded also. The blood pressure, ECG and also electroencephalogram, when necessary, are recorded at the same time and considered together with other data.

Effects of pentothal narcosis in dogs were studied first. In dogs in which myocardial damages, constrictive pericarditis and aortic stenosis were produced experimentally, the rate of reduction of the cerebral blood flow is conspicuously greater than in the normal animals. Although the cerebral blood flow drops when thoracotomy is done on normal dogs, it is far more conspicuous in those with aortic stenosis and constrictive pericarditis. With regard to the effect of bleeding, in normal dogs the decrease in the cerebral blood flow is rapid after the bleeding and rather small later on, but in those with myocardial damages the decrease is much greater after the bleeding and continues to be greater later on as compared with normal animals.

During various operations of the heart it is possible that anoxic anoxia occurs. In such cases, in normal dogs the cerebral blood flow increases suddenly to counteract this condition; in dogs with aortic stenosis or mitral stenosis, on the other hand, the increase of the blood flow takes much longer time, and in those with myocardial damages it does not increase at all. This seems to be due to a sudden drop of the cerebral vascular resistance in normal dogs but not in abnormal ones.

It may be restated in short that we have found that in surgical cases of acquired heart diseases, in general the cerebral blood flow decreases, the vascular resistance increases, the cerebral blood flow tends to further drop in response to various operative manipulations, and adaptive responses

against conditions which require increases of the blood flow are insufficient.

When normal dogs undergo stenotomy of the mitral or aortic valve, the cerebral blood flow drops considerably. This suggests that in those with heart diseases, effects on the cerebral circulation would be much greater. In cases of acquired heart diseases, the clogging of a secretion in the bronchus may cause loss of consciousness in a very short time. This is not experienced in other operations such as pulmonary resection indicates the greatness of the effects on the cerebral circulation.

IV. EXPERIMENTAL STUDIES ON THE DIRECT VISION OPERATION OF ACQUIRED CARDIAC VALVULAR DISEASES

From our experiences of heart operation on about 600 cases, we believe that from the standpoint of the operative technique only, the mitral stenosis cases are the most difficult ones. We have been convinced of this, as we have acquired more experiences. Most cases require scalpels or special contrivance, even if fingers are to be used. Especially in cases having stenosis under the mitral valve, it is very difficult and there is a danger of regurgitation. For the stenosis of the aortic valve certainty of operation is quite lacking under the present operative procedure. If however, operations under direct vision become possible, these difficulties would disappear naturally.

For this reason, we have made investigations on operations under direct vision of acquired heart diseases.

Of various techniques used in the operation under direct vision, we had taken for study first the hypothermia method. The methods of Bigelow, Lewis, Swan, ect., as shown in the figure 5, which

Fig. 5 The method of Bigelow, Swan, Bailey.

were reported at that time, used the cooling of the body except the head. From animal experiments we found that by their methods the interruption time cannot be prolonged much. According to our studies, by this method the lowering of the brain temperature is less than that of the body and the oxygen consumption of the brain does not decrease, and consequently the brain damages occur as the blood flow is interrupted too long. Therefore, realizing that it is necessary to reduce the temperature of the brain, which is especially weak, to counteract against the depletion of oxygen, we used a method of cooling selectively the head alone. We found that the oxygen consumption of the brain lowers more than the rest of the body and the time of interruption of the blood flow can be prolonged. (Fig. 6, A) This method was reported in October, 1954.

Fig. 6 The method of cooling.

Our studies made since then have shown that the cooling of the heart like that of the brain is advantageous for the interruption and that it is necessary to lower the temperature gradually for the heart. From this we realized that a gradual cooling of the body including the head can prolong the interruption time a great deal. (Fig 6, B) By this method the blood flow and the oxygen consumption of the brain as well as the heart are both reduced and the interruption time can be as long as one and a half hour in case of healthy dogs. Cases which we have operated by the direct vision method since October, 1954 total 37. In the first case operated under direct vision in our country, the modified method of Bigelow was used. In next 6 cases the head cooling was used. In the other cases, the cooling of the body including the head was employed. In twelve of these cases various other methods were used also. There are three other than these, in which operations under direct vision was used with the aid of the cardioscope. These are total 40 cases. (Table 1)

As shown in Table, with regard to congenital heart diseases, the operation is quite safe for child-

TABLE I CLINICAL CASES OPERATED UNDER DIRECT VISION AND LOW BODY TEMPERATURE. (AGE ABOVE 15)

Cases with myocardial damages					
Name	Sex	Age	Diagnosis	Time excluded	Result
M. W.	♂	19	Pulmonary stenosis	7' 30"	alive
H. M.	♀	42	Atrial sept. defect	5' 20"	"
T. I.	♀	29	"	6' 55"	"
M. F.	♀	26	Pulmonary stenosis	3' 55"	"
K. M.	♂	43	Atrial sept. defect	11' 7"	died
K. O.	♂	20	Vent. sept. defect	4' 45"	alive
S. M.	♂	19	"	5'	"
N. S.	♀	16	Pulmonary stenosis	2' 5"	"
S. K.	♀	17	Atrial sept. defect	8' 50"	"
F. Y.	♀	8	"	7' 40"	"
K. H.	♂	21	Vent. sept. defect	6' 30"	died
Y. S.	♂	29	Atrial sept. defect	7' 10"	alive
T. K.	♀	24	Vent. sept. defect	12'	died
E. K.	♀	19	"	7' 40"	alive

Cases with both myocardial damage and cyanosis					
Name	Sex	Age	Diagnosis	Time excluded	Result
H. M.	♂	18	Fallot	3'	alive
N. T.	♀	26	"	7' 30"	died
S. S.	♀	24	Vent. sept. defect	3' 8"	alive
M. T.	♂	21	Atrial sept. defect	7' 15"	"
K. K.	♂	24	"	5' 5"	died
R. K.	♂	25	Vent. sept. defect	8' 25"	"
S. Y.	♂	26	Atrial sept. defect	19' 45"	alive
N. A.	♀	26	Pulmonary stenosis	2' 20"	"

(age below 15)

Cases with neither myocardial damage nor cyanosis					
Name	Sex	Age	Diagnosis	Time excluded	Result
H. Y.	♂	9	Pulmonary stenosis	2'	alive
M. O.	♀	7	Vent. sept. defect	2' 25"	"
A. U.	♀	5	"	8' 25"	"

Cases with slight cyanosis					
Name	Sex	Age	Diagnosis	Time excluded	Result
S. K.	♂	6	Vent. sept. defect	4' 35"	alive

Cases with myocardial damages					
Name	Sex	Age	Diagnosis	Time excluded	Result
O. Y.	♂	4	Vent. sept. defect	2' 55"	alive
H. Y.	♂	10	"	3' 25"	"
M. Y.	♂	4	Atrial sept. defect	6' 20"	"
H. Y.	♂	5	"	3'	"
K. M.	♀	12	Vent. sept. defect	5'	"
J. H.	♂	14	Atrial sept. defect	8'	"

Cases with both myocardial damage and cyanosis					
Name	Sex	Age	Diagnosis	Time excluded	Result
A. K.	♂	6	Fallot	8'	died

ren under 15 years of age. Except one case of tetralogy of fallot where stenotomy and suture of the interventricular septum were carried out, there has been no case of death among eleven case operated by us. This death does not seem to be due to hypothermia, but possibly to the operational method. In cases of congenital heart diseases there is somewhat greater degree of danger when the hypothermia method is used for adults. That the danger is especially great when cyanosis or myocardial damages are not present was reported in the last fall. At present we are able to reduce the danger by using together the irrigation of the coronary artery and other methods. This is omitted here since it concerns with congenital heart diseases.

Since cases of acquired heart diseases are mostly not children and have myocardial damages, the interruption of circulation under hypothermia seems to be dangerous from our experiences on congenital diseases; and furthermore since in acquired heart diseases the cerebral blood flow drops and this tendency increases due to surgical procedures, the danger increases further. In dogs in which aortic stenosis, for example, is produced, the possible time of interruption under hypothermia is very much

shorter than in normal dogs.

Therefore, our method of cooling the body including the head has caused no death in congenital heart diseases of children unless cyanosis was present. We believe that the operation under direct vision of acquired heart diseases involves some danger even when this method is used.

The ideal method would be to interrupt the circulation while the normal amount of blood is being circulated by means of the artificial heart lung machine instead of using hypothermia method. However, at least at present there are various problems yet to be solved before a sufficient amount of blood can be circulated. Therefore, we determined the minimal necessary amount of blood and established a method whereby an amount of blood little larger than this volume is circulated. And we have made studies on the circulations of the entire body, especially in the brain and coronary arteries.

The method of circulating a minimal necessary volume was already reported in Lillehei's studies on cross circulation, but detailed investigation of the method has never been made. A part of our studies concerning mainly the cerebral circulation will be reported here.

Using dogs we ligated various branches of the internal carotid artery and connected, to the electromagnetic flow meter and other instruments. By changing the blood flow in various degrees, we determined the maximal and minimal limits.

A gradual increase of blood flow causes bleeding in the brain when it reaches 128cc/100gm/min. This is the maximal possible volume of blood flow for the brain of dogs. Above this volume cannot be circulated when artificial heart or artificial heart lung machine is used.

The minimal volume of brain irrigation under which dogs can survive was determined next. Lillehei thought that the animals can survive when the volume of blood circulating in the azygos vein is circulated and called it the "azygos factor". We found out that the so-called "azygos factor" was not sufficient. We found out also that the minimal necessary volume varies with the time of irrigation under interruption of the heart circulation.

The Table 2, shows the experiments with dogs. 10cc/min. is dangerous in total irrigation for 30 min.; for 20min. irrigation 10cc/min. is safe; for 10min. of interruption even 3cc/min. is safe. The intracardial operation requires at the most 20min.

TABLE II EXPERIMENTAL MEASUREMENTS OF THE MINIMAL NECESSARY BLOOD VOLUME FOR BRAIN CIRCULATION.

Circulation Time	No.	Circulation blood volume	Cornea Reflex early middle late	Resp. reflex	Light Reflex	Natural respiration	
30 min.	60	17	+	+	+	+	alive
	70	17	-	-	-	+	"
	53	14	+	+	+	+	"
	61	14	+	-	-	+	"
	68	14	+	+	+	+	"
	71	14	+	+	+	+	"
	55	11	-	+	+	+	"
	62	11	-	-	-	+	"
	58	10	+	-	-	+	died
	54	9	+	+	-	+	alive
20 min.	87	14	+	-	-	+	alive
	84	13	+	-	-	+	"
	81	11	+	-	-	+	"
	83	11	+	-	-	+	"
	86	8	+	+	+	+	died
10 min.	102	5	+	+	+	+	alive
	101	3	+	+	-	+	"
	103	0	+	-	-	-	died
	104	0	+	-	-	+	"
	105	0	+	-	-	-	"
8 min.	106	0	+	-	-	+	alive
	107	0	+	-	-	+	died
	108	0	+	-	-	-	"
5 min.	110	0	+	-	-	+	alive
	112	0	+	-	-	+	died

and usually less than 10 min.

Therefore, the actual volume of blood necessary is very small. For 30min. of interruption, for instance, there is no danger, if more than 14cc/100 gm/min. of blood is circulating in the brain.

In order to obtain 14cc/min. of cerebral blood flow at the least, we let various amount of blood flow into the aorta through subclavian artery and found that volume higher than this limit can be obtained, if 300cc/min. is irrigated. (Fig. 7)

Fig. 7 The comparison of the cerebral blood flow and volumes of blood sent into left subclavian artery under cardiac inflow occlusion.

Furthermore, we investigated changes of the cerebral blood flow by temporarily interrupting the aortic circulation in order to reduce the blood volume in irrigation. Since under an interruption the cerebral blood flow attains 20cc/min./100gm with an irrigation of 200cc, this volume is sufficient. Our animal experiments showed that the interruption of the descending aorta in within the limit of safely, if its time is within 20min., but if the time is prolonged to 30min., it may effect on the liver, spleen and spinal cord. However, considering the experimental results of De Bakly, Shinoi and Katsura that it is safer to use low temperature, we used the hypothermia method for the interruption of the aorta in clinical cases.

Similar experiments were carried out for the coronary circulation, but omitting details, only the conclusion will be presented here. By the method shown in the figure 8, the right coronary artery

Fig. 8 The method of measurement of coronary blood flow.

was ligated and the left coronary artery was irrigated experimentally. Since the result indicates that about 5cc/min./100gm cause ventricular fibrillation where as 6cc/min./100gm or more cause no such ill effects, the rate higher than the latter would assure safety. (Fig. 9)

According to professor Aizawa the average weight of the brain of the Japanese is 1300gm and 70 grams in dogs. Calculations based on these

Fig. 9 The minimal necessary blood volume for the left coronary artery.

figures indicate that if the minimal necessary volume^e for dogs is taken to be 14cc/min., the minimal necessary cerebral blood flow for the humans would be 182cc. Since the cerebral blood flow is 1/6 of the cardiac output per minute according to professor Aizawa, to obtain this volume, it would be necessary to send 1170cc/min. If an interruption of aorta is made simultaneously, 360cc per minute would suffice.

The ratio of the cerebral blood flow to the coronary blood flow obtained by Sheinberg's method is 3 : 2 in dogs and 31 : 7 in man. When the above stated volume of blood is sent, the coronary blood flow would be 10cc/min. in dogs and 35cc/min. in man. Since this reaches the minimal necessary coronary blood flow mentioned above, this volume is considered to be sufficient for the coronary circulation. Actual experiments with dogs indicated that without interruption, 300cc per minute while with interruption 200cc cause ventricular fibrillation under complete irrigation. Applying these results to clinical cases, we have performed intracardial operations under direct vision by carrying out irrigations considered on the basis of the minimal necessary volume.

Furthermore, studies were made to find whether warmer or cooler temperature of the blood is advantageous. When the cerebral blood flow is kept constant, irrigation of warmer blood causes an increase of the oxygen consumption whereas that of cooler blood causes a decrease.

The concentration of oxygen in the tissue of the cerebral cortex was determined by oxygraph. When the cerebral blood flow is kept constant, irrigation of warmed blood causes the lowering of the pressure of the cerebral artery and an increase of the oxygen concentration in the cerebral tissue. On the other hand irrigation of cooled blood causes

a rise of the pressure of the cerebral artery and a decrease of the oxygen concentration in the tissue. While it is necessary that the oxygen consumption is lessened in the brain when the circulation is interrupted under hypothermia, for operations performed while blood flow is being kept with irrigation of the minimal necessary volume, a warmed blood which has a greater capacity of supply of oxygen seems to be more advantageous. This point is now planned to be further investigated.

V. CLINICAL CASES OF ACQUIRED VALVULAR HEART DISEASES SURGICALLY TREATED UNDER DIRECT VISION

The results obtained by the above mentioned experiments were applied to clinical cases for the operation under direct vision.

The following three methods were used for irrigating the minimal necessary quantity of blood described above through the coronary and cerebral circulation.

The first method is to irrigate coronary circulation with oxygenated blood through aorta while the cerebral and corporal circulation were interrupted. (Fig. 10. A) Hypothermia was used to prevent the brain damage.

Fig. 10 The operative method under direct vision of acquired valvular diseases.

The oxygenated blood sent into the aorta flowed into the coronary artery and then into the left auricle where it was removed through a tube inserted there. Two cases of mitral insufficiency were interrupted its circulation for five minutes and 55 seconds in the first case and 9 minutes in the second case, and operated directly in suturing and shortening and shortening the fibrous annulus of the mitral orifice under direct vision. (Fig. 11) This operative method was proposed by one of us (Sakakibara) already.

Postoperatively the patients were quite well and the systolic murmur disappeared.

In this method, however, cerebral blood flow

Fig. 11 Direct vision operation for Mitral Insufficiency.

had to be occluded and it was not desirable to occlude the cerebral circulation in case of the acquired heart diseases, as mentioned already. So that the next method was applied to one case of mitral stenosis.

The oxygenated blood was sent by a pump through a cannula inserted into the aorta from the left subclavian artery; and then the descending aorta and the right subclavian artery were occluded. (Fig. 10. B)

The cardiac occlusion was achieved by Kiser's ligation. By means of this method the blood returning to the vana cava was removed through a cannula inserted into the subclavian vein. The time of interrupting circulation was 7 minutes the anteromedial commissure and subvalvular stenosis were divided under direct vision. (Fig. 12) The

Fig. 12 Left atrium is opened and the fibrous annular ring now begins to be sutured.

post-operative condition was very good. In our method the amount of blood to be removed is small, for low temperature and minimal necessary quantity of blood flow are used. However, it is unreasonable that the blood poured into the vessel has to be removed.

Therefore, we used another method in which the heart circulation was maintained by an artificial heart, while the blood was oxygenated in patient's own lung. (Fig. 10. C) (Fig. 13)

Fig. 13 The heart operation under direct vision using artificial heart machine.

A cannula was inserted into the left auricle and connected to a pump, and a cannula was put into the left subclavian artery from the pump. Left atrioventricular orifice was clamped with stan-sky clamp just superior of coronary artery. Although the blood circulation was almost completely stopped, the pinching by assistant's fingers as the tip of the clamp was somewhat pressed against the septum caused a complete cessation of the circulation.

By this method we operated on a twenty-two years old male for the aortic stenosis.

After the circulation was interrupted by the procedure described above, approximately 4 cm. of incision was made at the apex of the left ventricle and the aortic valve was directly seen. A small cut was made at one commissure and then commissure was incised by finger. The artificial heart was operated for 13 minutes and 40 seconds; the amount of blood sent out was 800-1000 cc. per minutes; and the time of the cessation of the circulation was 6 minutes and 20 seconds. The postoperative course was good and the symptom has been considerably improved.

So far as we investigated, we could not find out any report of successful operation under direct vision for acquired heart diseases.

We think our success in the surgery of this area is the result of our researches on the determination of the minimal necessary volumes of blood circulation in cerebral and coronary arteries.

VI. CONCLUSION.

The brain circulation in patients of acquired heart diseases were studied. The brain circulation in these cases are somewhat different from that of congenital heart diseases.

The influence of surgical operations on the brain circulation was discussed.

On the basis of theses studies, the operations under direct vision of the acquired heart diseases were investigated.

The minimal necessary amount of blood flow in cerebral or coronary arteries was determined by animal experiments.

The results was developed to the open surgery of acquired heart diseases in clinical cases.

Four successful cases were demonstrated.

We are grateful to Dr. Aoyama, president of the last meeting, Prof. Hara, and Prof. Nuki M. O. president of the Present meeting.

We are also indebted for their cooperation to all members in the Heart Institute and Surgical department of the Tokyo Women's Medical College.

本誌の用紙は日本加工製紙會社井口誠一氏の寄贈によるものです。

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第20卷・第5號

昭和31年8月15日印刷

昭和31年8月20日發行

誌代年 1200圓 (送料共)

1冊 100圓 (送料共)

編集兼發行人 平 川 顯 名
京都大學醫學部内科第三講座

印刷所 河北印刷株式會社
京都市南區唐橋門脇町二八

發行所 京都大學醫學部内科第三講座
日本循環器學會

電話 吉田 4111 番
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