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Open Heart Surgery in Infants with an Aid of Hypothermic Anesthesia

by

YORINORI HIKASA, HITOSHI SHIROTANI, KISAKU SATOMURA, RYUSUKE MURAOKA, KOKI ABE, KUREO TSUSHIMI, YOSHIO YOKOTA, SHIGEHITO MIKI, JUN KAWAI, ATSUMI MORI, YOSHIFUMI OKAMOTO, HISAAKI KOIE, TOSHIHIKO BAN, YOSHIO KANZAKI and MICHIO YOKOTA

From the 2nd Surgical Division, Kyoto University Medical School
(Director : Prof. Dr. CHUJI KIMURA)

CHUZO MORI, TETSURO KAMIYA, TOKIO TAMURA and AKIRA NISHII

From the Department of Pediatrics, Kyoto University Medical School
(Director : Prof. Dr. ROKURO OKUDA)

YOSHIYUKI ASAWA

From the Department of Anesthesiology, Kyoto University Medical School
(Director : Prof Dr. AKIRA INAMOTO)

I. INTRODUCTION

It is a well known fact that hibernating animals accumulate much lipids in their bodies prior to their hibernation. A clue of this research was that we could have performed ideal hypothermic anesthesia provided that we followed the natural providence of hibernation.

II. PHYSIOLOGICAL SIGNIFICANCE OF EFA (ESSENTIAL FATTY ACIDS) THAT PLAY IMPORTANT ROLL DURING HYPOTHERMIC ANESTHESIA

As the result of recent research as to lipid metabolism, lipid has been elucidated to have a special physiological significance that nothing else can substitute and function of lipids appears to originate from EFA that can not be synthetized in the living body. For instance, an individual with lack of EFA has insufficient amount of EFA in his skin and needs increased intake of water because of increased insensible evaporation. It also shows that capillary permeability of skin is elevated from the lack of EFA. Nowadays capillary vessel is said to have a structure shown in Fig. 1. Basement membrane itself fills intercellular pathway which is a kind of cell slit. Administration of ANTU that is fat soluble substance selectively destroys basement membrane and this fact implies that it is lipid abundant tissue (Fig. 2). HERKEN recently concluded biochemically that it contains much lipids as we presumed before. As Fig. 3 shows, cell membrane is widely recognized as a kind of lipoprotein. From these stand-points, it has been presumptive that an individual with shortage of EFA should have increased capillary permeablity. As shown in Fig. 4, shortage of EFA and oral administration of excessive water easily induce edematous swelling of the alveolar epithelium of lung which is abundant in collagen fibres

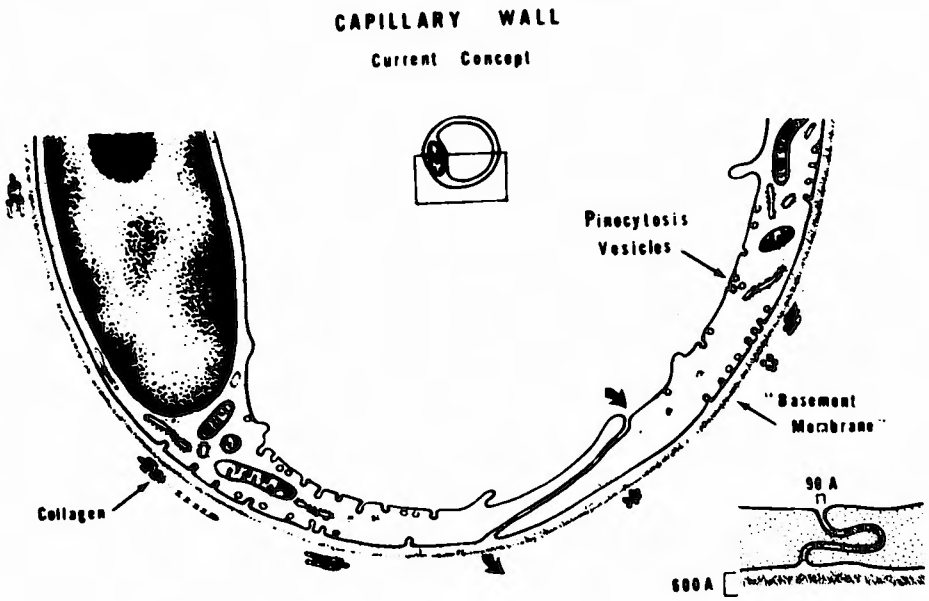

Fig. 1.

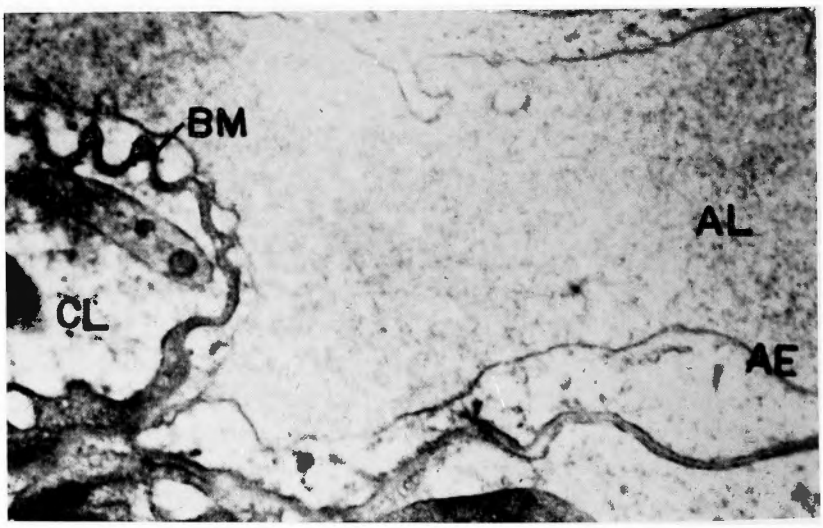

Fig. 2. Selective and destructive change (wavy extension) of basement membrane induced by ANTU injection. (Rat)

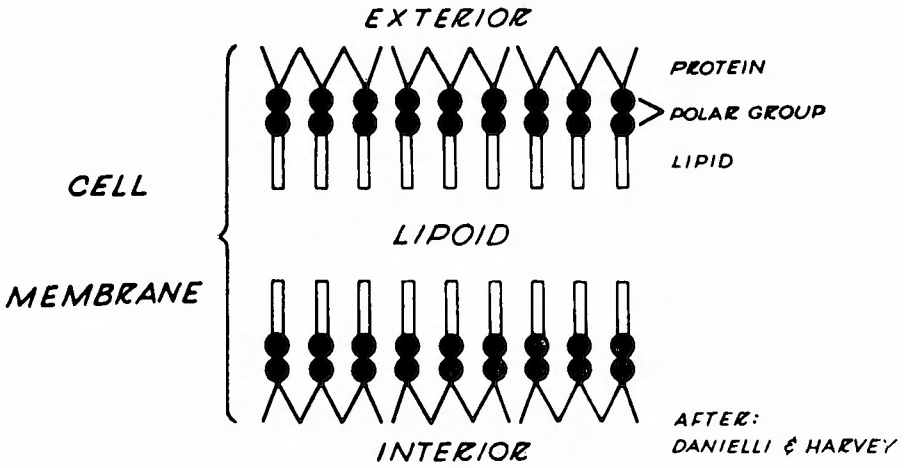

Fig. 3 Cell membrane

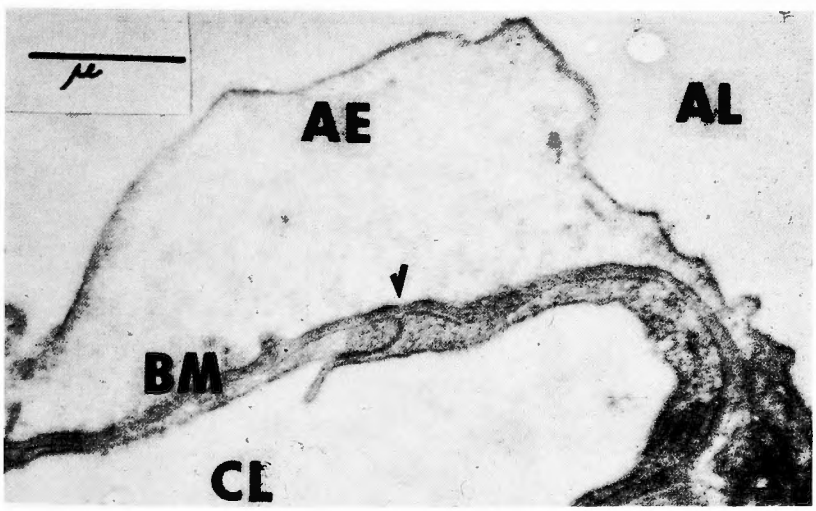

Fig. 4. Per oral water loading. (The alveolar epithelial cells swell up. —EFA-deficient rat.) (×55,000) Arrow : Intercellular pathway.

and has the lowest tissue pressure against the development of pulmonary edema. Electronmicroscopic findings as edematous swelling of alveolar epithelium and "schleusenartige Öffnungen" are first seen in the part of epithelium that corresponds to the existing part of intercellular pathway (Fig. 5). Reflecting on these facts, the shift of intravascular fluid is mainly mediated by intercellular pathway and the extent of capillary permeability depends on characteristcs of basement membrane which is abundant in EFA and simultaneously on the charactor of cell membrane.

On the other hand, it became apparent that hypothermia accompanies undesirable side effects as hemoconcentration and gives rise to disturbances of peripheral circulation. It is presumed that EFA would prevent them. In facts, as shown in Fig. 6, administration of EFA prior to hypothermic anesthesia prevented hemoconcentraton and peripheral circulation was maintained properly. Myocardium is a organ which has the highest activity among the muscle system and contains abundant EFA as much as in adrenal gland and liver and concentration of it in myocardium is much higher as compared with it in smooth muscle and skeletal muscle.

Table 1 Mean value of fibrillation threshold under hypothermia (Dogs. Rectal temp. 18°～19℃)

Control	Administration of Essential Fatty Acids	Administration of Essential Fatty Acids plus Dimethylamino-ethanol
3.90 Volt	11.25 Volt	>13.00 Volt

Mitochondria has recently been postulated to have a structure as shown in Fig. 8. Shortage of EFA causes the changes of membrane characteristics and gives rise to so-called dissociation of oxidative phosphorylation. EFA acts on enzyme system with above mentioned structural attitude. And shortage of EFA

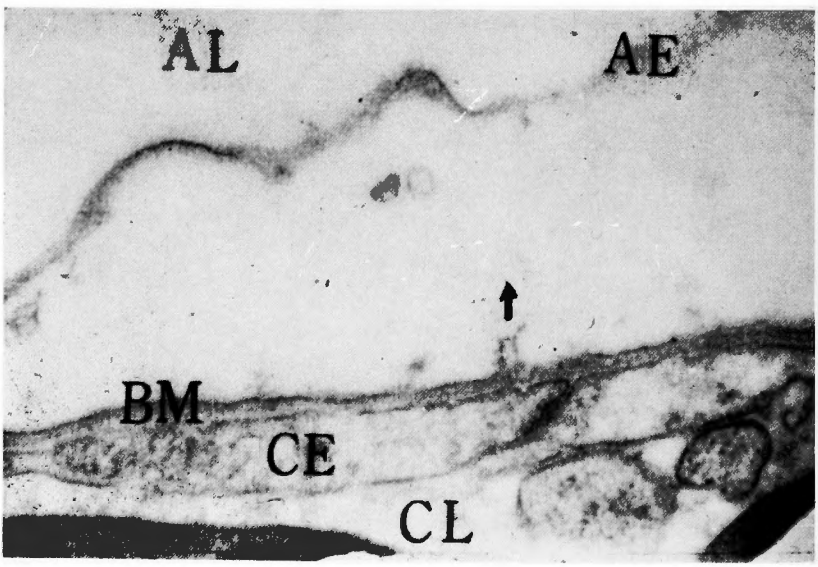

Fig. 5. Per oral water loading. (The arrow shows so-called "schleusenartige Öffnungen, which is the condition of destruction of cell membrane of alveolar epithelium. EFA-deficient rat.) (×73,200)

reduces the resistance towards tissue anoxia. From these knowledges, it is presumed that intentional administration of EFA would prevent ventricular fibrillation which is frequently a fatal complication of hypothermic anesthesia. Electrical threshold for ventricular fibrillation in the dog who was cooled to 20°C. of his rectal temperature was measured and that threshold was apparently elevated in the group that was given EFA previously (Table 1).

BERGSTRÖM's recent study elucidated that a potent substance named as Prostaglandins is playing the important roll for adjustment of blood pressure and heart rate and that substance is produced from EFA. BING and ANFINSEN regarded the roll of free fatty acids in myocardium as energy source of heart contraction. And true appearance of lipid

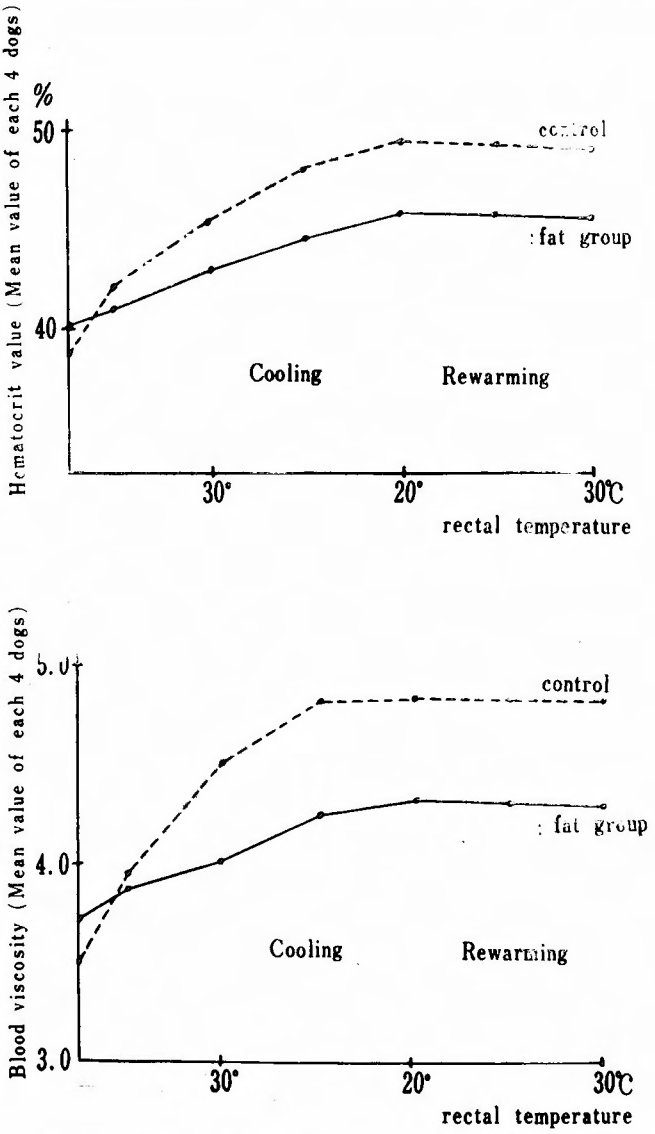

Fig. 6. Changes in hematcrit value and blood viscosity during profound hypothermic anesthesia.

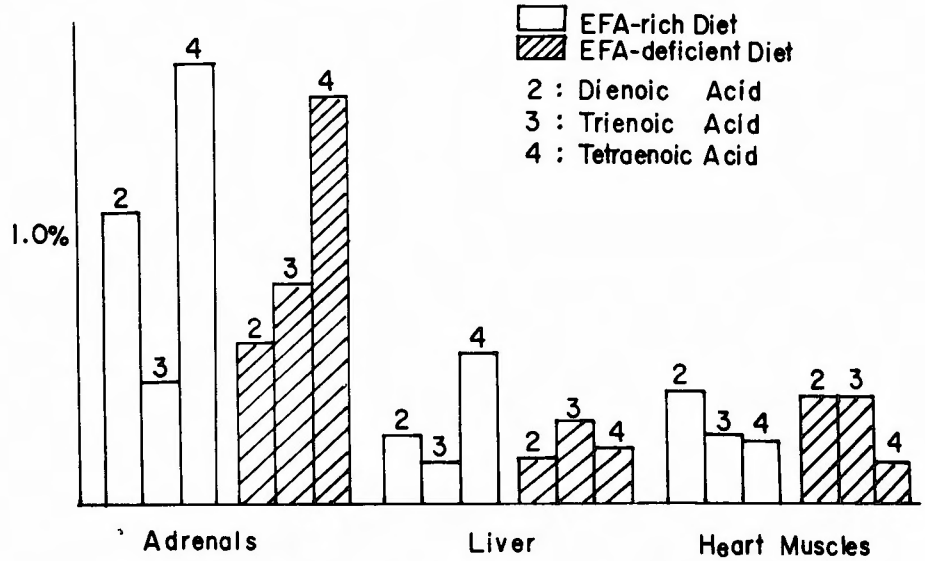

Fig. 7. EFA contents in various organs of the rats fed either EFA-rich diet or EFA-deficient diet.

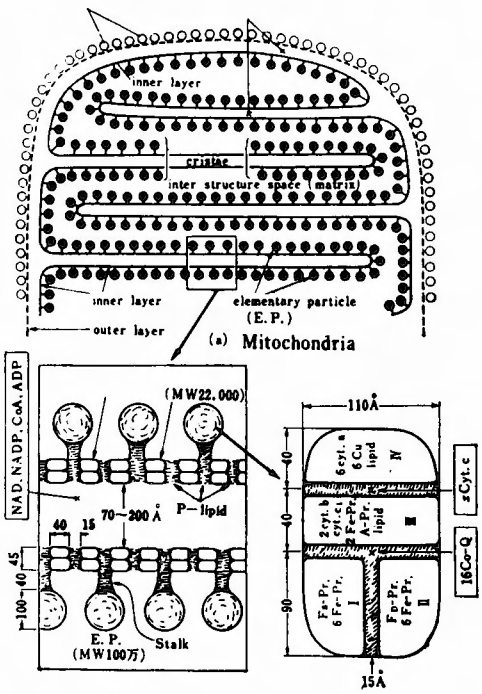

Fig. 8. Schema of mitichondria.

storage seen in hibernating animal seems to be made clear in thus way. Special attention should be drawn to the fact that EFA is contained in the adrenal gland in its highest concentration and it is pertaining to the maintenance of adrenocortical capacity of individuals.

III. CLINICAL APPLICATION OF HYPOTHERMIC ANESTHESIA WITH THE USE OF SURFACE COOLING AND REWARMING

Polarographic current flow in the brain of hypothermic animal predicts the availability of 60 minutes complete circulatory arrest at the rectal temperature of 20°C. (Fig. 11). We lowered animals' temperature to 20°C. with an aid of surface cooling and caused complete circulatory arrest after the injection of previously cooled YOUNG's solution into the root of aorta.

After right ventriculotomy on these animals, we performed resuscitation and rewarming experiments and consequently con-

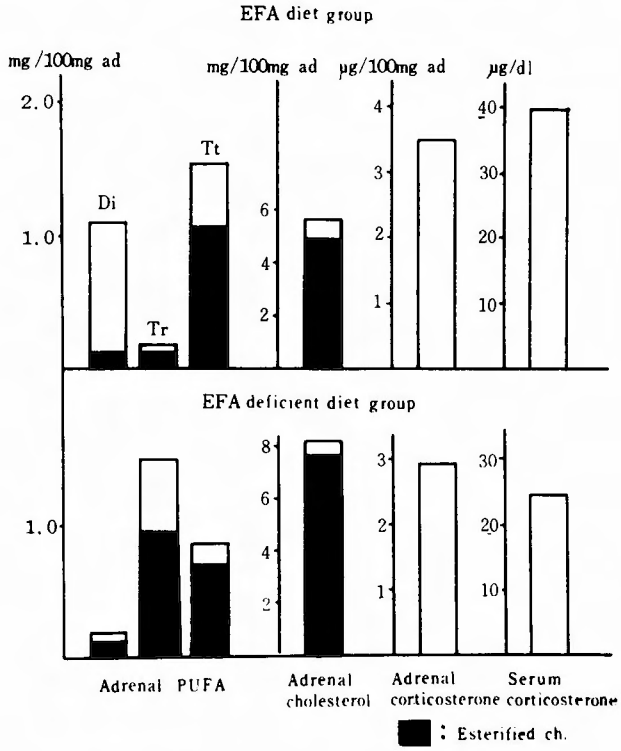

Fig. 9. Comparison of cholesterol, corticosterone, polyenoic fatty acids (PUFA) concentration contained in adrenal gland and of serum corticosterone level between the group with EFA administration and that with EFA deficiency (in resting condition). Di : Dien, Tr : Trien, Tt : Tetraen.

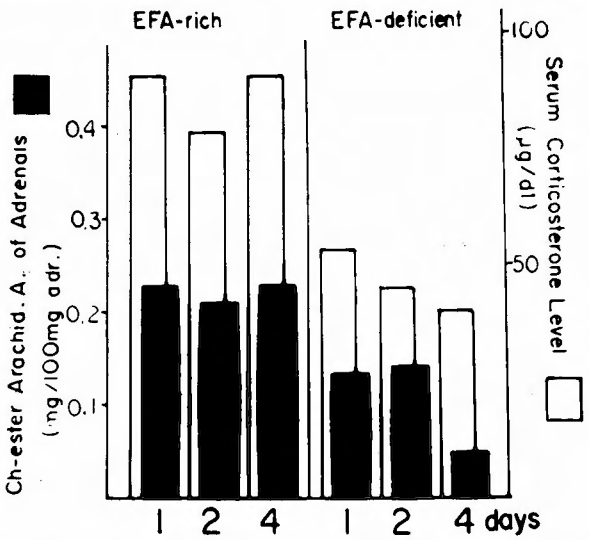

Fig. 10. Effect of ACTH on serum corticosterone and arachidonic acid esterified with cholesterol in adrenals of rats (Daily administration of ACTH-Z 3 I.U. for 4 days)

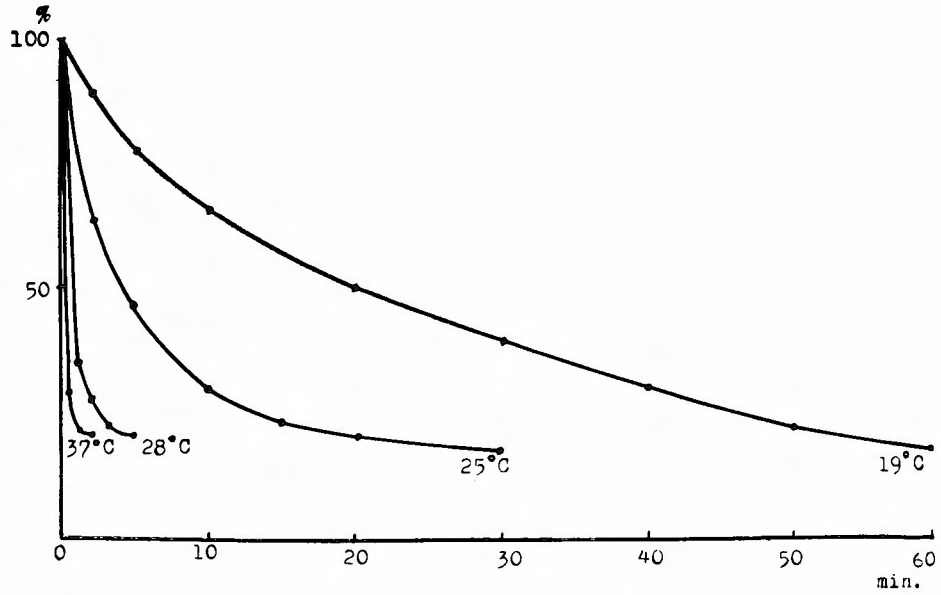

Fig. 11. Polarographic current flow (Brain)

firmed the availability of 50 minutes circulatory arrest at the rectal temperature of 20°C. As Table 2 shows, group that was preoperatively given FFA and Vitamin E as antioxidant revealed very low incidence of ventricular fibrillation and excellent survival rate in comparison with control group. Based on such fundamental research, EFA and Vitamin E were routinely administered to the patient for one week to ten days prior to hypothermia and patient was cooled to 22°C. of his rectal temperature without applying autonomic blocking agents under inhalation anesthesia of O. E. F. maintained in such a depth as to prevent cold shivering. Cardiac arrest was artificially induced by the injection of YOUNG's solution that was previously cooled to 4°C. and radical corrections of congenital anomalies as ASD, VSD and PS were safely performed with satisfactory results until the introduction of Pemco's pump-oxygenator-system into our clinic (Fig. 12). At that period, manual heart massage and surface rewarming in combination with intrathoracic rewarming that had been devised by HASHIMOTO Clinic of Nagoya University were employed. With acquisition of Kay-Cross pump-oxygenator-system, open heart surgeries, for adults and elder children were undertaken with an aid of extracorporeal circulation and not uncommonly disposable oxygenator was used to economize the blood.

IV. APPLICATION OF HYPOTHERMIC ANESTHESIA TO INFANTS

Infants with congenital heart anomalies who are in so-called critical phase are usually operated upon under extracorporeal circulation with remarkably poor results (Table 3). They have recurrent respiratory infections and/or anoxic attacks and their physical development is usually retarded severely. At least, best indication of hypothermic anesthesia may be such infants who can not survive, even with strenuous pediatric treatments, to a age when they will be safely operated upon under extracorporeal circulation.

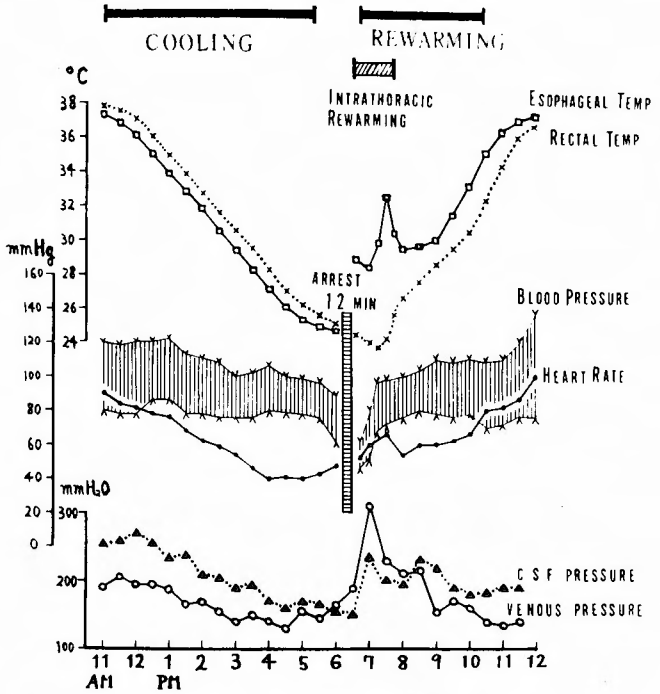

Fig. 12. Valvulotomy of a pure pulmonary stenosis under direct vision. ♂ 17 years old. Weight 60kg. Duration of total circulatory occlusion 12 min. 3 sec. Lowest rectal temperature 24.7 C.

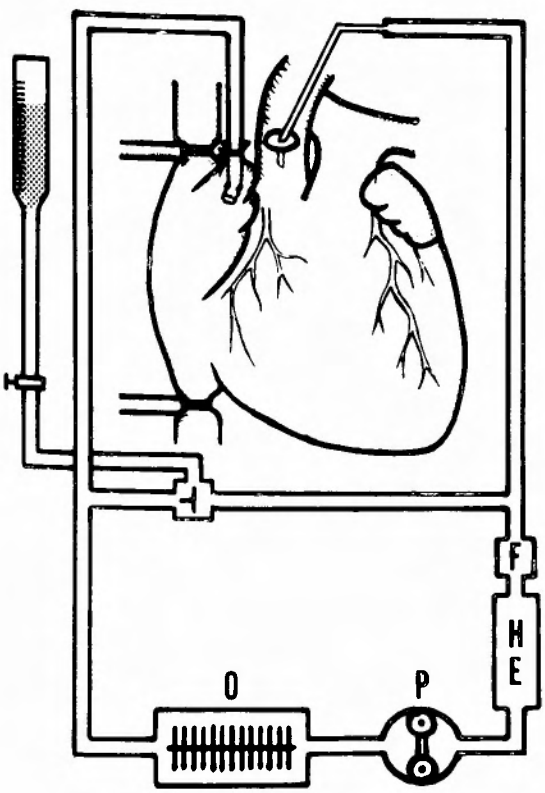

Fig. 13. Extracorporeal circuit employed at rewarming period.

As our result indicates, in our initial several cases, we massaged the heart after radical operation and rewarmed the patient by the combination of intrathoracic irrigation and surface rewarming. During our initial series, we lost a case of V. S. D. from the breakage of patch graft that was applied to defect. After that experience, venous cannula which was inserted to right auricle at cooling period was connected to the circuit shown in Fig. 13. As soon as intracardiac repair was completed, flow rate of 30 to 50 cc/kg/min. was employed for partial perfusion without heart massage and patient was rewarmed to 30°～32°C. at the rate of 0.5°C. min. with subsequent surface rewarming (Figs. 14 and 15).

Infants who urge cardiac surgeons to run the risk of open heart surgery usually have large V. S. D. associated with moderate to severe pulmonary

Table 2 Long survial experiments after ventriculotomy under hypothermia

	No. of dogs	Rectal temperature (℃)	Time of circulatory interruption (min)	No. of long survivors	No. of deaths	
Control	6	17～19	20～30	3	3	
Fat group	11	18～20	20～30	10	1	Died of pyothorax
Fat group	5	18～22	50	5	0	

Table 3 Results of radical operation for VSD in infants under one year of age

	No. of Cases	No. of Deaths	Mortality
Kirklin	34	14	41%
Cooley	31	13	42%
Sloan	17	4	24%

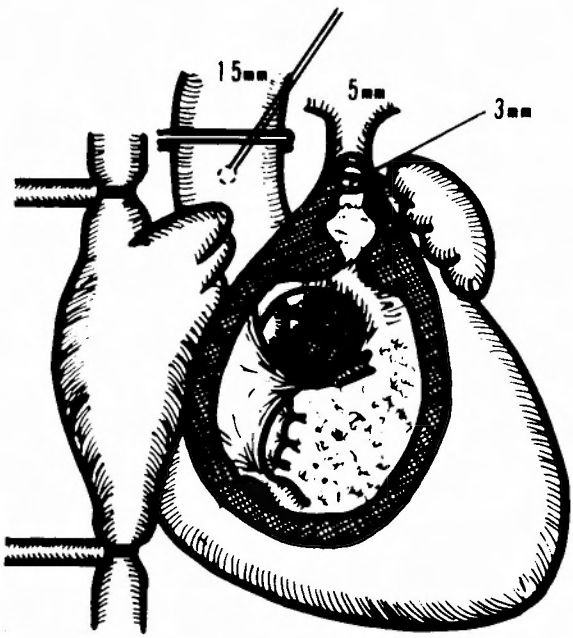

Fig. 14. Operative findings in infant with tetralogy of Fallot (15-month-old, 8.8kg, male)

hypertension. These infants have respiratory insufficiency due to recurrent air way infection and show lowered base excess. The more severe respiratory infection the patient has, the more remarkable is the extent of metabolic acidosis. From these reasons, it is not advisable to apply the central cooling method that accelerates development of metabolic acidosis and so far as hyothermic method for open heart surgery in infants is concerned, surface cooling should be adopted. And we also introduced the technique of extracorporeal circulation to the rewarming period of hypothermia (Figs. 16 and 17).

V. CONCLUSION

As shown in Table 4, 43 infants who weighed less than 9.2 kg were operated upon with the use of above mentioned technique. Among 43 infants, 36 had V.S.D., 4 had tetralogy of FALLOT and rest of two infants had A.S.D. and V.S.D. plus P.S. respectively. Rectal temperature was lowered to 17°C.～25°C. with an avarage of 22°C. and duration of circulatory arrest diversed from 15 minutes to 75 minutes with an avarage of 37 minutes. All infants survived the operation except 3; the first expired from the breakage of patch graft due to manual heart massage in the rewarming period which was applied in our initial series, and the second died from respiratory insufficiency due to the rupture of bulla. The third was 18-month-old infant with remarkable cyanosis (O_2 saturation of femoral artery blood was 84.5%) and history of anoxic spell. He had predominant right to left shunt preoperatively and expired on the 2nd postoperative day. Some problems still remain unsolved as to surgical curability of V.S.D. associated with more right to left

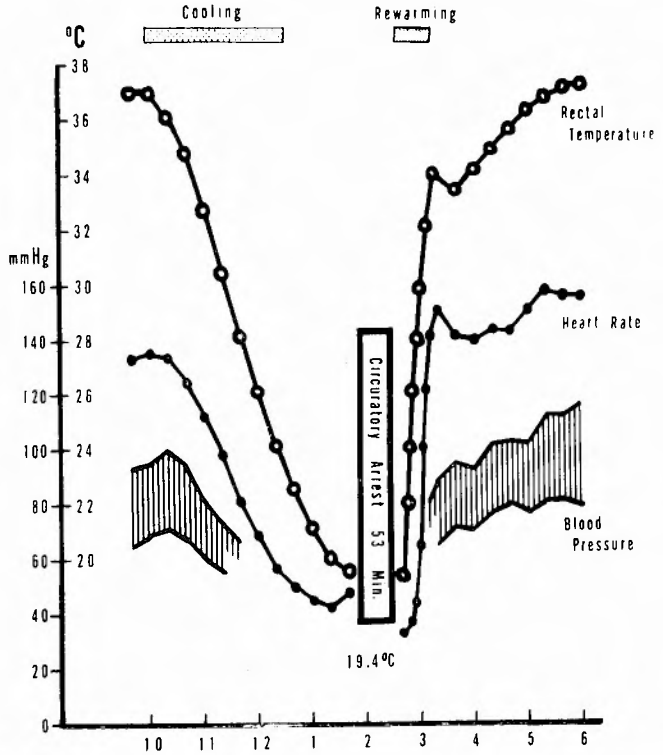

Fig. 15. Process of cooling and rewarming in infant with tetralogy of Fallot.

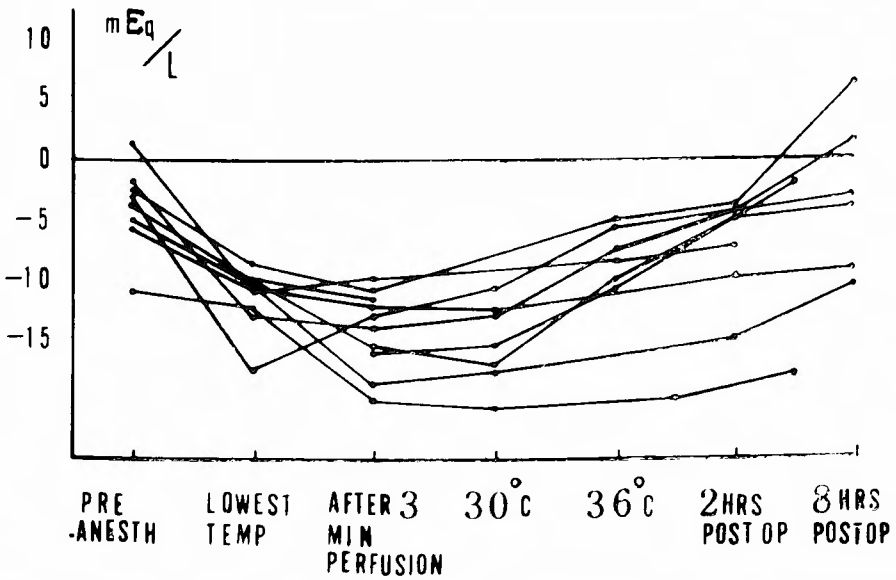

Fig. 16. Serial change of base excess at cooling and rewarming period (infant with V. S. D.)

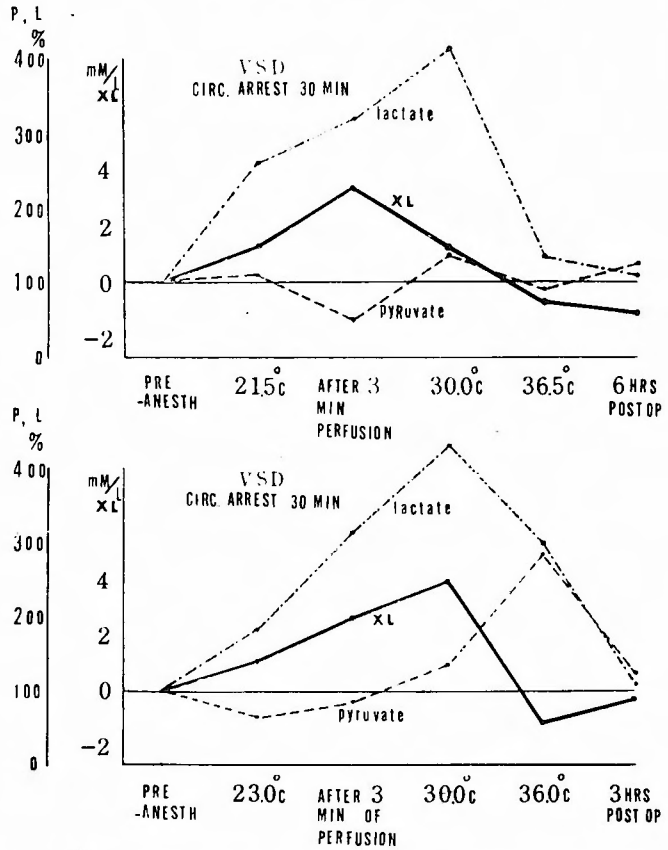

Fig. 17. Typical cases showing relationship of rectal temperature and excess lactate

Table 4 Open heart surgery in infancy (Body weight less than 10kg)

	No. of Cases	Surv.	Died
ASD	2	2	0
VSD	36	33	3
VSD & PS	1	1	0
T. of Fallot	4	4	0
Total	43	40	3

Rectal temperature 17 C～25 C m. 22°C
Circulatory arrest 15'～75' m. 37Min.

shunt than left to right shunt. Most of infants who were undertaken the radical operation in their infancy were severely ill preoperatively and were necessitated patch graft for closure of large V.S.D.. They usually had PA/AO systolic pressure ratio of more than 0.61 and pulmonary arteriolar resistance of more than 10 units which is equivalent to 800 dynes. sec. cm^{-5} (Table 5).

Most of the infants with large V. S. D. who expired without surgical intervention in

Table 5 VSD : PA/AO pressure ratio and pulmonary arteriolar resistance

(1 Unit : 80 dynes. sec. cm^{-5})

PA/AO PR	No. Cases	No. Deaths	PAR	No. Cases	No. Deaths
← 0.4	0	0	←- 5	1	0
0.41 → 0.6	5	0	5 → 10	5	0
0.61 → 0.8	13	0	10 -→ 20	11	0
0.81 -→	18	3	20 -→	16	3

Size of defect min. 5 × 7 mm
max. 21 × 25mm

the pediatric ward at Kyoto University Hospital showed pulmonary artery systolic pressure of more than 60 mm Hg and pulmonary arteriolar resistance of more than 800 dynes. sec. cm^{-5} and severely disabled infants to such extent are strictly selected for candidates of radical operation at the present time.

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和文抄録

乳児開心根治術

京都大学医学部外科学教室第2講座（指導：木村忠司教授）

日笠頼則・城谷 均・里村紀作・村岡隆介
阿部弘毅・都志見久令男・横田祥夫・三木成仁
河井 淳・森 渥視・岡本好史・鯉江久昭
伴 敏彦・神崎義雄・横田通夫

京都大学医学部小児科学教室（指導：奥田六郎教授）

森 忠三・神谷哲郎・田村時緒・西井 晃

京都大学医学部麻酔学教室（指導：稲本 晃教授）

浅輪喜行

われわれはあえて乳児期に外科的療法を行なわなければ救命し難いと思われる高度の肺高血圧症を伴なう心室中隔欠損症，度重なる Anoxic Spell を伴なう Fallot 氏四徴症など，小児科的療法によつて症状の改善をみない，発育が著しく障害あるいは停止した乳児の先天性心疾患に対する外科的療法に検討を加え，次のような結果を得た．

(1) 乳児期開心根治術を行なうに当つては，予め1週間ないし10日間不可欠脂酸補給源としてソーヤ・レシティンあるいは50%リノール酸エステルとその Antioxidant であるビタミンEを投与したのち，表面冷却による超低体温麻酔下（直腸温20℃内外）に行なうことが最も安全かつ合理的である．

(2) 開心根治術完了後は，右心耳と大動脈起始部の間に熱交換器を含む小型人工心肺による部分体外循環を行ない，心蘇生と復温を同時に行なう方法が代謝面からみてきわめて有利であり，かかる方法によれば，手術局所の再破損をまねく怖れのある心マッサージを行なうことなく安全かつ確実に心蘇生を図かりうると共に，Surgical A-V Block 発生時にも安全に対処しうるし，また Fallot氏四徴症に対する根治術後に充分な補助循環を行ないうるという数々の利点が認められた．

(3) 以上の方法によつて心房中隔欠損症2例，心室中隔欠損症36例，心室中隔欠損症＋肺動脈狭窄症1例，Fallot 氏四徴症4例の計43例に対して乳児期開心根治術を行ない，心室中隔欠損症の3例を失なつたにすぎないという好成績をおさめえた．

(4) さらに，乳児期開心根治術症例の術後管理の特殊性とその対策について検討を加え臨床的立場からその対策を画立しえた．