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Intra-Aortic Balloon Pumping in Infants

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Abstract

From October 1981 to August 1984, intra-aortic balloon pumping (IABP) was applied in nine patients who were from 2 months to 7 years old, weighted from 3.4 to 18 kg. In eight patients, the miniaturized intra-aortic balloons made in house with 1.0 to 10 ml volumes mounted on No. 3.5 to 6.0 F catheters were used. Effective diastolic augmentation of arterial pressure was accomplished in seven and suprasystolic diastolic augmentation was accomplished in five. There were three long-term and three short-term survivors. Conclusively miniaturization of the equipment has permitted IABP to be used effectively in pediatric patients.

Introduction

Intra-aortic balloon pumping (IABP) has become a standard mode of treatment for perioperative low cardiac output syndrome and cardiogenic shock after myocardial infarction in adults[2,5,7]. However, IABP has been used little in children. The only report of use of the commercially available IABP in children suggests that it is not successful in those who are under 5 years of age[11]. Our experience with both in vitro and in vivo testing of our house made small balloon catheters in small animals with three different pumping modules convinced us that this valuable method of circulatory surpport could be used in children[3,15]. Our cooperateres in Salt Lake City have reported their initial successful experience in eight patients in 1983[16]. This report describes our initial experience in nine patients who underwent IABP during and after open heart surgery.

Materials and methods

Seven patients had previously undergone open heart surgery for correction of the lesions

Key words: Intra-aortic balloon pumping, Pediatric IABP, Mechanical support, Congenital heart diseases, Polyurethane catheter.
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Table 1. Results with the use of pediatric IABP

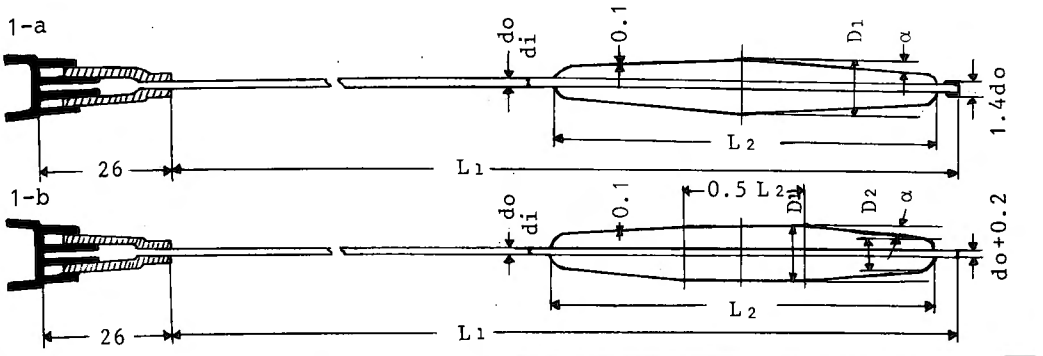
No.	Name	Age	B.W.	Diagnosis	Sizes of Balloon	Effects of IABP	Prognosis
1.	Y. A.	18 mo	6.2 kg	DORV, TGA	2 cc	Unstable	Table death
2.	T. N.	10 mo	5 kg	TOF	1 cc	Good	Table death
3.	T. M.	4 y	11 kg	TGA, VSD	3 cc	Good	Weaning (−) 37 hrs of pumping
4.	Y. Y.	2 mo	3.4 kg	TAPVD	1 cc	Good	Table death
5.	A. M.	7 y	18 kg	TA, TGA, VSD, PS	7 cc	Poor	Weaning after 2 days
6.	I. A.	3 y	14 kg	DORV, PA, PDA	6 cc*	Unstable	Obstraction of Ao (?)
7.	Y. M.	5 y	14.5 kg	TGA, DORV, PS	10 cc	Good	Weaning after 4 days
8.	I. T.	6 mo	5.1 kg	VSD	3 cc	Good	Weaning after 15 hrs
9.	M. H.	10 mo	6.8 kg	TGA, VSD	3 cc	Good	Weaning (−) 7 days of pumping

* commercially available SMEC pediatric balloon catheter, Others; house made IAB, DORV; double outlets of right ventricle, TGA; transposition of great arteries, TOF; tetralogy of Fallot, VSD; ventricular septal defect, PA & PS; pulmonary atresia & stenosis, TAPVD; total anomaly of pulmonary venous drainage, PDA; patent ductus arteriosus, TA; tricuspid atresia.

listed in Table 1. In two cases, the balloon catheters were pumped during and after open heart surgery. Balloon catheters were introduced by cutdown through the common femoral artery with or without the USCI sheath catheter in 6 cases, and through the external iliac artery in 3 cases. Introduction of all balloon catheters was accomplished in the operating room. Three of the catheters were connected to the Utah heart driver, two catheters were connected to the Datascope System 82 pumping module modified with a pediatric volume-limiting chamber, and the last four catheters were driven by the SMEC Model 1300i assist system. In initial seven cases of nine, the balloon catheters were inserted only after maximum use of pharmacologic support had failed to improve the patients low cardiac output syndrome (LOS). In the last two cases the balloon catheters were inserted intentionally prior to the extracorporeal circulation because of suspecting of postoperative LOS.

A 6 ml commercially available balloon catheter made by SMEC was used in the 3 years old patient listed in Table 1 (No. 6). In all other either a 1 ml, 2 ml, 3 ml, 4 ml, 5 ml, 7 ml or 10 ml volume balloon made in house (Fig. 1) was used. These balloons were mounted respectively on a No. 3.5 F, 3.5 F, 4.5 F, 4.5 F, 4.5 F, 5.5 F and 6 F catheter and were specially manufactured more recently by Toray Industry, Research Laboratory (in Otsu, Japan). The diameters of the balloons were varied from 4.5 mm to 10 mm and the lengths of the balloons were varied from 80 mm to 150 mm as listed on the Table of the Fig. 1. The catheters used were made of polyvinyl chloride coated with the segmented polyurethane, and the balloons were made of the antithrombogenic segmented polyurethane.

In all cases, the electrocardiograph was used for triggering the inflation and deflation of balloon and adjustments were made for inflation and deflation time to permit optimal alteration of the patient's pulse contour from the left radial artery. The balloon size used and duration and outcome of IABP in each patient are shown in Table 1.



Balloon size	(I)	(II)	(III)	(IV)	(V)	(VII)	(X)
di mm	0.69	0.69	0.97	0.97	0.97	1.31	1.70
do mm	1.15	1.15	1.50	1.50	1.50	1.85	2.30
do F	3.5	3.5	4.5	4.5	4.5	5.5	6.0
L_1 mm	300	300	350	400	450	500	600
L_2 mm	80	80	100	120	120	125	150
D_1 mm	4.5	6.0	6.0	7.0	8.0	9.0	10.0
D_2 mm	3.3	3.3	4.0	4.0	4.0	5.0	6.0
Balloon volume ml	1.1	1.9	2.8	3.8	4.8	6.5	9.7

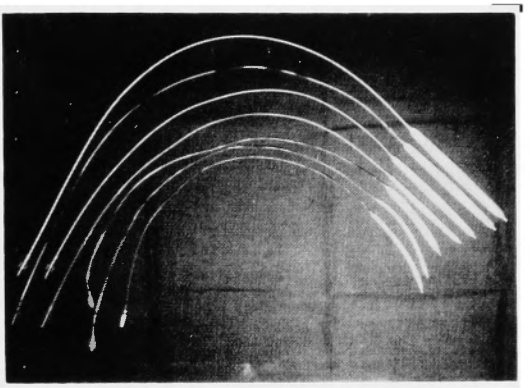


Fig. 1. Intraaortic balloon catheters specially miniatured in house. 1 ml, 2 ml, 3 ml, 4 ml, 5 ml, 7 ml and 10 ml balloon were mounted on a No. 3.5 French (F), 3.5 F, 4.5 F, 4.5 F, 4.5 F, 5.0 F and 6.0 F catheter respectively. 1-a; The originally designed balloon catheter, 1-b; The more recently improved balloon catheter.

Patient histories

Patient No. 1:

Y.A. was a one and half-year-old boy with double outlet right ventricle and D-transpositions of great arteries who underwent open heart repair of ventricular septal defect and outflow anomaly of aortic root by the intraventricular method with a pericardial patch. A right ventriculotomy was required to position the large patch necessary to cover his ventricular septal defect and outflow tract of aorta, and the patient was placed on cardiopulmonary bypass (ECC) for a total of 75 min. The patient developed postoperative LOS and when he could not be weaned from ECC after an additional 45 min of support, pediatric IABP was considered to be applied. A 2 ml IABP was inserted into the thoracic aorta through the right iliac artery with a cutdown method. Because of the relatively large tip and balloon diameter of the balloon catheter designed at the initial stage and used in this case (Fig. 1, 1-a), highly skilled techniques were required for insertion of the balloon catheter through the small iliac artery even after the insertion was failed through the common femoral artery. When IABP was started, the monitoring scope displayed initially slight augmentation of diastolic pressures, although not at suprasystolic levels, at a rate of 154 beats/min. After a short period of time, no effect of IABP was detected. In spite of

vigorous pharmacologic support (8.0 μg/Kg/min dopamine, 2.2 μg/Kg/min nitroprusside, and 2.0 μg/Kg/min epinephrine), the condition of the patient continued to deteriorate and he died on the operating table 45 min later. Autopsy revealed a small valve orifice and a mildly hypoplastic left ventricle. No thrombus formation and no injury of aortic wall were found.

Patient No. 2:

T.N. was a 10-month-old, 5.0 Kg girl who underwent radical repair of a tetralogy of Fallot. After the 90 min repair on cardiopulmonary bypass she had low cardiac output in spite of intravenous dopamine support. Approximately 3 hr after she could be weaned from ECC, she returned to the intensive care unit. However, her postoperative bleeding had continued until to be uncontrolable, and she was taken back to surgery. During the transportation and the surgery, her pressures continued to drop in spite of blood transfusion and vigorous pharmacologic support (15.0 μg/Kg/min dopamine, 0.2 μg/Kg/min iv isoproterenol and 0.2 μg/Kg/min epinephrine). A decision was made for a trial with IABP, and a 1 ml balloon was introduced via the right external iliac artery as in the previously described patient. The position of balloon was checked by palpation of the thoracic aorta, but no alteration of the left radial pulse was observed. She died in the operating room 30 min later. An autopsy was not performed. Application of IABP seemed to be too late.

Patient No. 3:

T.M. was a 4-year-old, 11 Kg boy, who underwent a Musterd procedure for D-transposition of the great arteries and repair of a ventricular septal defect and pulmonary artery banding. Considerable difficulty was experienced in weaning the patient from cardiopulmonary bypass, and he was placed on IABP prior to return to the intensive care unit. A 3 ml IAB was inserted without any difficulties into the thoracic aorta by a cutdown on the right common femoral artery. Effective diastolic augmentation of arterial pressure was obtained with IABP at a rate of 160 beats/min. Better diastolic augmentation at suprasystolic levels, however, was noted when the heart rates came down to approximately 140 beats/min. The clinical status of patient showed progressive improvement with a steady rise in blood pressure improved peripheral perfusion and urine output. At the following early morning when the patient started to have sinus techycardia and arrythmia over 180–210 beats/min IABP lost the satisfactory diastolic augmentation, and the patient failed to improve in spite of IABP and vigorous pharmacologic support (20 μg/Kg/min dopamine, 0.5 μg/Kg/min phentolamine, 0.2 μg/Kg/min epinephrine). He died 37 hrs after IABP was instituted. An autopsy was not performed some are unable to explain exactly the main causes of death.

Patient No. 4:

Y.Y. was a 2-month-old, 3.4 Kg boy who underwent repair of a total anomalous pulmonary venous drainage (inferior cardiac type). A 1 ml balloon was inserted into the thoracic aorta by the cutdown on the right external iliac artery without the use of a Dacron sleeve which are usually used in adult patients. IABP was started at the beginning of cardiopulmonary bypass as a pulsatile assist device. The satisfactory pulsatile pulse was noted on the left radial monitoring

pulse. After the 95 min repair on cardiopulmonary bypass, he continued to have low cardiac output, and the patient's condition was gradually improved with the assist of IABP. Excellent diastolic augmentation of arterial pressure was obtained at a rate of 180 beats/min until the heart was compressed in order to repair bleeding from the suture lines on the left atrium. After the bleeding was stopped, no alteration of the left radial pulse was observed, and the patient failed to recover. He died on the table 6 hrs after IABP was instituted. Autopsy revealed irregular suture lines on the left atrium and the pulmonary venous sinus, and a numberous micro-hemorrhages on the ventricular myocardium. There was no evidence of thrombus formation or of aortic injury from IABP. Size of the 1 ml balloon (ϕ 4.5 mm) seemed to be perfect as desired in the descending aorta.

Patient No. 5:

A.M. was a 7-year-old, 18 Kg girl who was the oldest patient in our series, and underwent a Fontan procedure for D-transposition of the great arteries, tricuspid atresia, ventricular septal defect and mild pulmonary stenosis. After the 95 min repair on cardiopulmonary bypass, she continued to have low cardiac output in spite of vigorous pharmacologic support (6.0 μg/Kg/min dopamine, 1.2 μg/Kg/min nitroprusside, and 0.12 μg/Kg/min epinephrine). When considerable difficulty was experienced in weaning from the ECC after an additional 40 min of support, a 7 ml IAB was introduced through a Gore-tex® sleeve attached on the left common femoral artery. It effected an immediate improvement in her blood pressure and urine output, although the efforts of IABP were not significant. Only slight diastolic augmentation was observed at a rate of 165 beats/min and no significant depression was obtained on the left atrial pressures which went down from 25 mmHg to 18 mmHg immediately after and however to 15 mmHg after approximately 1/2 hr of IABP. The clinical status of patient showed progressive improvement with a steady rise in blood pressure, improved peripheral perfusion and urine output. By the following morning she had improved to the point that the rate of IABP could be decreased to every second beat. IABP was maintained for the next 2 days. This patient was the first long-term survivor. She left the hospital on her thirty postoperative day and is now doing well 26 months after surgery.

Patient No. 6:

I.A. was a 3-year-old, 14 Kg boy, who underwent a Rastelli operation for double outlet right ventricle, pulmonary atresia and patent ductus arteriosus. After the 95 min repair on cardiopulmonary bypass, he experienced considerable difficulty in weaning from ECC even after an additional 40 min of support, and vigorous pharmachologic support (16 μg/Kg/min dopamine, 2 μg/Kg/min nitoprusside, and 0.15 μg/Kg/min epinephrine). A 6 ml IAB commercially supplied from SMEC was introduced into the thoracic aorta via the right external iliac artery by a cutdown method. However, immediately after IABP started, urine output decreased and poor peripheral perfusion to the lower extremities was recognized. Those clinical signs suggested severe obstruction of the descending thoracic aorta with even a deflated balloon. Therefore the balloon was concluded to be not effective, and exserted. The patient hemodynamics, however,

Sheath sizes for the pediatric IABP balloon catheter in use of percutaneous insertion

Balloon volume ml	1	2	3	4	5	7	10
with guid wire	+	+	−	−	−	−	−
Sheath size F	6	6	7	8	8	9	9

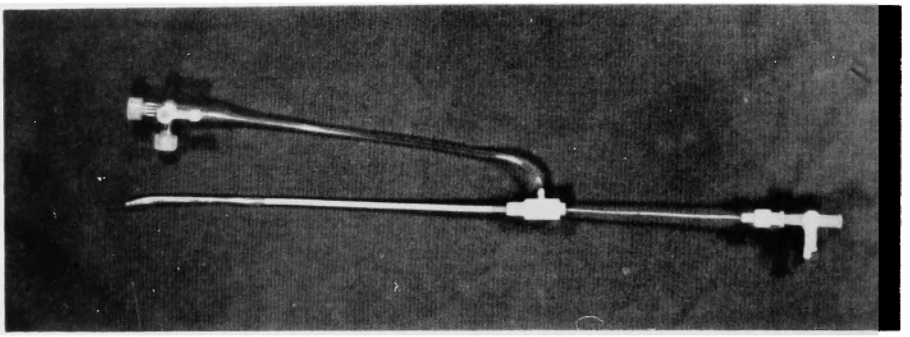


Fig. 2. A balloon catheter through a USCI pericutaneous seath catheter. Lists of balloon volumes and sizes of USCI sheath catheters. F; french size, +; Either 1 ml or 2 ml balloon catheter requires a guide wire to be inforced for insertion.

were remarkably improved and his urine output also was improved. He left the hospital on his thirty postoperative day and he is doing well 6 months after surgery.

Patient No. 7:

Y.M. was a 5-year-old, 14.5 Kg boy with corrected transposition of great arteries (TGA), double outlets of right ventricle (DORV), pulmonary stenosis (PS) and mitral regurgitation. He underwent a Rastelli's operation with a external conduit mounted a SJM valve (No. 21) and a mitral valve replacement with a SJM 27. After ECC, he failed to respond to intoropic drugs and his mixed venous oxygen went down to 27 mmHg. A 10 ml more recently improved IAB (Fig. 2) was pericutaneously introduced into his thoracic aorta via the right common femoral artery by using a No. 9 French USCI sheath catheter. Immediately after IABP was started, IABP effected a remarkable improvement in his blood pressure with suprasystolic augmentation. The satisfactory diastolic augmentation was obtained even at rates that went up to as high as 180 beats/min. His urine output increased from 0.4 ml/Kg/hr to 7.5 ml/Kg/hr, and his mixed venous PO_2 rose to 43 mmHg. IABP was maintained for the next 4 days. He is doing well 8 months after IABP.

Patient No. 8:

I.T. was a 6 month-old, 5.1 Kg girl who underwent repair of a large ventricular defect. After surgery her pressure continued to drop in spite of the administration of intravenous dopamine given at a rate of 20 μg/Kg/min. IABP was instituted with a 3 ml balloon catheter, which was easily inserted via the right external iliac artery by a cutdown method and utilizing assist of a No. 7 French USCI sheath catheter. Her mixed venous PO_2 had risen from 19 mmHg to 27 mmHg 3 hr after IABP. After 15 hr her condition was stable and the IABP was removed without event. However, she died from pulmonary complications on her sixteenth day. Autopsy

permission was denied.

Patient No. 9:

M.H. was a 10-month-old, 6.8 Kg girl, who underwent repair of D-transposition of great arteries and ventricular septal defect by a Senning procedure. Considerable defficulty was experienced in weaning the patient from cardiopulmonary bypass, and he was placed on IABP 1 1/2 hr after return to the intensive care unit. A 3 ml IAB was inserted pericutaneously via the right common femoral artery. In spite of effective diastolic augmentation with the IABP at rates of 150 to 180 beats/min, and the administration of intravenous dopamine (15 μg/Kg/min) and nitoprusside (2 μg/Kg/min), the patient's condition could not be dramatically improved, and she died 7 day after IABP was instituted. Autopsy revealed a hypoplastic right ventricle with a marked subaortic obstruction that appeared mild on an angiogram. There was no evidence of thrombus formation or of aortic injury from the prolonged period of IABP.

Results

Only three patients (No. 5, 6 and 7) in this group of nine who had IABP were long-term survivor, and another patient (No. 8) was a short-term survivor (16 days) after IABP. Two additional patients (No. 3 and 9) could survive for 37 hours and 7 days after surgery, although they could not be completely weaned from IABP and died. In our opinion, survival in these six patients would not have been possible without IABP.

Autopsy performed in three patients revealed no evidence of thrombus formation or of aortic injury from the prolonged period of IABP, although the clinical course in the patient (No. 6) who was introduced a commercially supplied 6 ml I.A. balloon suggested severe obstruction of the thoracic aorta even with a deflated balloon and of the common femoral artery with the large catheter (8 French).

Of the three patients who died on the Table (No. 1, 2 and 4) and of two patients who died in the short postoperative period without complete weaning from IABP (No. 3 and 9), three had satisfactory alteration of the pulse contour with IABP. In two of these five, suprasystolic augmentation of diastolic pressure was accomplished.

With IABP, three out of the six patients (No. 3, 5, 6, 7, 8 and 9) who experienced an initial evidence of clinical improvement were accomplished with the progressively improved peripheral perfusion, increased urine output and improved blood gas determination. Only two of the six could not be accomplished with these satisfactory efforts. In only one (No. 6), peripheral perfusion and urine output increased when the IAB exserted.

In a single patient (No. 1), IABP with a 2 ml balloon did not result in any recognizable alteration of the pulse contour or deter a rapidly deteriorating course. The failure of IABP in this case seemed that a decision was made too late for a trail with IABP. The satisfactory efforts with IABP which was initially obtained, could not be observed at the late stage of the patient No. 2. These two cases showed very similar phenomena.

Balloon catheters were removed when the patient responded well or no longer needed the

circulatory assistance (patient No. 5, 7 and 8), when they were of no valve (patient No. 2) or when death seemed imminent or had occured (patient No. 1, 3 and 9). Removal of the house made IAB was never necessary in the eight patients (No. 1, 2, 3, 4, 5, 7, 8 and 9) because of obstruction of the thoracic aorta or of ischemia of the lower extremity. In only one case (No. 6) who was applied a commercially supplied IAB, early removal was required.

The newly improved house made IAB (Fig. 1, 1-b) could be introduced easily into the thoracic artery though the external iliac or common femoral arteries, by the pericutaneous method though the USCI sheath catheters (Fig. 2), in the last three cases (No. 7, 8 and 9).

As an initial clinical application of the pediatric IABP, all of the patients selected for this group of nine were postoperative children with a totally repaired congenital heart disease. None was a preoperative patient, while there were two patients in whom IABP was started to institute during the extracorporeal circulation as a pulsatile assist. In these two cases, IABP was started just after the total bypass perfusion with a cardiopulmonary bypass system was initiated. All of autopsy done revealed that the radical repair intended had been successfully performed.

Discussion

The circulatory assistance from IABP is achieved by displacing intra-arterial blood volume. This displacement occurs with pneumatic inflation of the balloon placed in the thoracic descending aorta immediately after closure of the aortic valve, and deflation of the balloon just before the onset of ventricular systole. The displacement of the blood volume result in a drop in aortic end-diastolic pressure, which in turn decreases left ventricular impedance (after load). Ideally, peak arterial pressure is shifted into diastole, resulting in increased tissue perfusion that includes the coronary circulation. The increased supply of oxygen to myocardium and the reduced demand for left ventricular work results in an increase in the myocardial oxygen supply/demand ratio[10,12]. Right ventricular function has also been shown to improve with IABP in adult suffering from cardiac shock[4].

The concept of IABP was first tested in a mock circulation model in 1961 by Dr. S. D. MOULOPOULOS, a cardiologist from Athens who was working in the laboratory of Dr. W. J. KOLFF at the cleveland clinic[8,13]. The first clinical application of circulatory assistance was reported in 1968 by KANTROWITZ, et al.[6], and it became established as a standard mode of treatment for cardiogenic shock and perioperative low cardiac output syndrome in adults during the middle and late 1970s. IABP has, however, been used little in children. There are only two reports in the literature describing the use of IABP in children. One is by POLLOCK, et al.[11], and another is by L. G. VEASY, et al.[16]. The former suggested that it could be of value in children over 5 years of age but could not be used in those less than 5 years old, primarily because the commercially available balloons and catheters were too large. In addition, it was felt that aortic elasticity in the young child prohibited effective diastolic augmentation. The large balloons were considered to be responsible for renal failure, and in two of the 14 patients severe lower extremity ischemia required removal of the balloon catheter.

In 1977 our group began work to develop equipment that would provide the electronics and

pneumatics necessary for the higher rates and smaller displacement volumes that would be necessary in IABP in infants and children. Idea of this work was proposed by a son (J. KOLFF) of Dr. W. J. KOLFF and the research studies and development of IAB were investigated completed by one of the authors (H. FUKUMASU), et al.[3]. The in vitro and in vivo testing of small balloons (0.75 to 10.0 ml) in cats and small dogs conviced us that IABP could be used effectively in infants and children[15]. The characteristics of our house made pediatric IABP were not only the utility of a small balloon and a small catheter, but also alteration of inner diameter and length of catheter which are essential to reduce the impedance of a balloon catheter against quick air-flow. Thickness of the balloon which is made of polyurethane is also improved to be as thin as a balloon catheter could be easily introduced through the common femoral artery which is relatively smaller in children, and could be strong enough to be tolerable against IABP driving pneumatic pressure.

In 1981, our group made a decision to start initial clinical application of the pediatric miniaturized IAB in both United States and Japan. The group of Dr. L. G. VEASY, et al. in Salt Lake City has reported outcomes of their initial experience in 1983[16]. They reported that four of the eight patients placed on their IABP had remarkable benefits of IABP and two of them whose survival would not have been possible without IABP are long-term survivors. Effective augmentation of diastolic pressure was accomplished in seven of the eight patients and supra-systolic diastolic augmentation was accomplished in four. In only one patient was IABP observed to be ineffective. Mose recently Dr. L. G. VEASY has personally informed that additional 8 children had been placed on IABP and six of the eight patients were long-term survivors. They also reported that there was a noteworthy lack of complications.

The results of our initial experience were almost the same as Dr. L. G. VEASY, et al. reported[16]. Contrary to previous clinical experience[11], we were very pleased to find that the pediatric IABP could be of value in children, even in those less than 1 year old. Inflation and deflation of our balloon could match heart rates even faster than 140 beats/min (L. G. VEASY said 130 beats/min)[16], while IABP was more effective pumping every other beat at rates exceeding 160 beats/min. Urine output characteristically and dramatically increased after institution of IABP. There was no evidence of thrombus formation, of aortic injury, or of embolization either clinically or at autopsy in any of the patients. None of the patients underwent heparinization during IABP. Continuous monitoring of the patients pulse contours and repeated adjustment of inflation and deflation timing were necessary to maintain optimal alteration of the arterial pulse contour with IABP.

At the time IABP was instituted all patients were receiving inotropic support, which was continued until the patient became stable and could be weaned from pharmacologic support. The use of inotropic drugs with α-adrenergic agonist effects may decrease the compliance of the systemic arterial bed of the younger patient and may enable more effective, while our polyurethane balloon has ability of exceeding expasion with high pneumatic driving pressures to minimize the disadventages of elastic aortic wall against displacement of blood volumes with IABP in younger children which were described by POLLOCK, et al. before[11].

Table 2. Preoperative use of IABP in cases with various congenital cardiac diseases.

Type of Lesion	On Defects
ASD, VSD	Beneficial
PDA	Deleterious
TOF	Deleterious
TGA, TA, PA, TAPVD	Beneficial
TOF+PDA TGA+VSD/PDA	Beneficial
Truncus	Deleterious

ASD; atrial septal defect, VSD; ventricular septal defect, PDA; patent ductus arteriosus, TOF; tetralogy of Fallot, TGA; transposition of great arteries, TA; tricuspid atresia, PA; pulmonary atresia, TAPVD; total anomaly of pulmonary venous drainage, Truncus; truncus arteriosus.

Our experience was limited and catheter selection was done quite empirically. Generally, we attempted to use the largest balloon catheter that we felt could be accommodated by the patient. Aortic diameter was estimated[1,9,14] and the balloon catheter was placed on the surface of the patient to evaluate whether the balloon would extend beyond the twelfth thoracic vertebra to avoid compromise of the celiac and renal vessels. For the smaller patients, this posed a little difficulty while there were many choices of 1 ml to 5 ml (4.5 mm to 8 mm diameter and 8 cm to 12 cm length) balloon catheters (Fig. 1). We attempted to select a balloon size that would be 40% to 60% of the estimated stroke volume.

In this limited initial experience, the pediatric IABP was considered for use when the patient did not have a lethal lesion and possibility of the presence of a significant residual anatomic defect had been excluded, whenever pharmacologically refractive low cardiac output syndrome is present. Specific indications for use of IABP could include cardiac index dropping below 2.0, mixed venous PO_2 dropping below 20 mmHg, and urine output dropping below 1 ml/Kg/hr. It is important, however, to realize that IABP can only augment cardiac output and should not be delayed until augmentation would have minimal or no effect. Of our cases, the patient No. 1 could not have any benefits from IAB pumping and the patient No. 2 could not have satisfactory augmentation of diastolic pressures at the late stage of IABP, although autopsy or clinical course revealed the balloon volumes and sizes were enough satisfactory to be effective.

Additional experience will be needed to define specific indications, proper time for intervention, and factors that can predict successful or unsuccessful outcome. Although in our initial clinical application of the pediatric IABP was considered for use in only postoperative children, our previous animal studies clearly revealed that IABP could be of value even in preoperative patients with some kinds of congenital heart diseases[3]. IAB pumping decreases end-diastolic and subsequently systolic pressures of left ventricle, and results in reducing beneficially the left to right shunt through ventricular septal defect and also atrial septal defect, but deleteriously increases the left to right shunt through cannals at the level of aorta (Table 2).

Conclusion

While it is unlikely that IABP will ever be used as frequently in children as it is in adults, the availability of appropriately sized equipment should enable IABP to become an accepted and valuable mode of circulatory support in pediatric patient. Our limited clinical experience has not proved IABP to be a panacea for postoperative or preoperative (not in all cases) low cardiac output syndrome, but it has demonstrated quite conclusively that it can be successfully used, even in infants. We hope that our initial experience with IABP will encourage other groups to use this mode of circulatory assist in children.

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和文抄録

小児新生児用 IABP の臨床治験

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成人重症心疾患患者に対する機械的循環補助手段としての大動脈内バルーンパンピング（IABP）の効果は，近年広く循環器内科医にまで認められ，多くの患者がその恩恵を充分に受けるようになった．しかし，小児，特に新生児重症心疾患患児では未だその効果は認められていない．従来市販の小児用 IABP バルーンカテーテルが，ただ単に成人用バルーンカテーテルの製作上の知識技術を小児の特長を充分検討することなく流用製作しただけのものであるため，その効果が充分発揮されていない．小児新生児における循環器系の特長は，1）(大)動脈壁のコンプライアンスが大きい，2）必要心拍出量のバラエティが大きく多種サイズのバルーン容積を必要とする，3)相対的に心拍出量が大きい，心拍数も相対的に速い，さらに4)下行胸部大動脈以下の下半身の動脈が細い，特に大腿動脈は歩行開始前小児において細い，など解剖学的生理学的異なる点があげられる．これらの特長のために，従来市販の絶対的に大きすぎるカテーテル上に相対的に小さすぎるバルーンを装着したものでは，その効果が充分発揮されないだけでなく，かえって下半身の血行障害を来し，副作用が大きく効果なしと結論された．

この結論に対し，今回開発してきた小児用バルーンカテーテルは，各種（1, 2, 3, 4, 5, 7, 10 cc）サイズを揃え，相対的に充分細いカテーテル上に，充分大きなバルーンを装着することに工夫を加えた．カテーテルは短くし，心拍数への応答性も高めた．最近，臨床応用例8例（従来市販のもの応用例1例）を経験し，良好な成果を証明することができた．小児の場合特に薬物効果に反応する巾が大きい．そのため最終手段と考えられる機械的補助手段の適応が過遅延となりがちである．しかし，その場合にも効果は充分認められた．8例中3例で社会復帰に成功，5例に充分な効果を認めた．従来言われてきたような不安定な効果例はわずか2例であった．