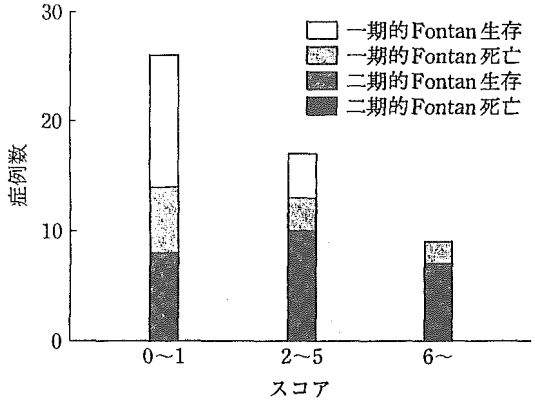

図 1. 一期的・二期的 Fontan 手術症例のリスクファクタースコアと生死（遠隔死亡を含む）の関係

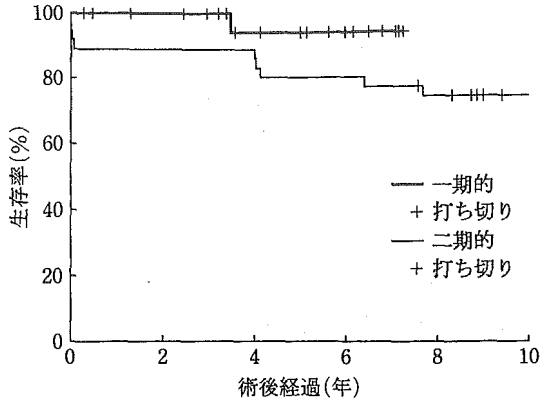

図 2. 生存率の比較
5 年生存率：一期的 80.0±6.8%，二期的 93.8±6.1%（p 値：NS）
10 年生存率：一期的 74.2±7.4%

表 4. 遠隔生存のためのリスクファクター
（Cox 回帰分析）

	p 値	オッズ比
男性	0.47	1.56
手術時年齢	0.16	1.11
手術時期(1970 年～/1995 年～)	0.075	14.22
AVVR	0.38	0.21
TAPVC	0.33	5.56
無脾症	0.56	2.80
PA banding	0.60	0.57
B-T シャント	0.82	1.13
不整脈	0.50	1.74

AVVR：房室弁逆流，TAPVC：総肺静脈還流異常，
B-T シャント：Blalock-Taussig シャント

II. 結　　果

早期死亡は 4 例（前期 4 例，後期 0 例），遠隔死亡は 12 例（前期 11 例，後期 1 例）であった．早期死亡率は 6.8%（前期 12%，後期 0%，p＝0.10），遠隔死亡率は 21% であった．5 年生存率は 85.2±4.9%（前期 80.0±6.8%，後期 93.8±6.1%），10 年生存率は 79.6±6.0% であった（図 2，p 値：NS）．早期死亡原因は低心拍出症候群，遠隔死亡原因は敗血症，脳膿瘍，不整脈，突然死などであった．遠隔死亡のリスクファクターを表 4 に示す．Cox 回帰分析において有意なリスクファクターは認められなかった．

III. 考　　察

当院では肺血管抵抗指標（pulmonary vascular resistance index：PVRI）が 4 u•m² 以下の症例を安全に Fontan 手術を行える適応としている．BCPS と他の肺血流路の閉鎖術を介して二期的に Fontan 手術を施行する場合は上大静脈（SVC）圧が 15 mmHg 以下の症例が必然的にその適応となる．表 3，図 1 で示したように，Choussat ら[3]による Fontan 手術適応基準の危険因子に基づいて症例を検討したところ，後期になるにつれ high risk 症例が増加しているにもかかわらず，死亡症例は high risk 群のみとなっていることがわかった．前期では Choussat ら[3]の基準から逸脱していた high risk 症例が Fontan 手術に到達できなかったとういこととともに，正確な肺血流量評価が行われていなかったのではないかということが考えられる．後期では BCPS を介することにより正確な肺血流量評価が可能となり，手術症例の選出に有用であったと思われた[5]．遠隔死亡率に関しては，Kaplan-Meier 法を用いた log-rank 検定による生存率の比較では有意差を認めなかった．一期的 Fontan 手術の観察期間が約 20 年に対して，二期的 Fontan 手術は開始してからまだ 8 年であることから，引き続き経過観察を行い，再度検討する必要があると考

える．術式としては一期的手術には自己組織による修復を第一とした[6]．二期的手術に対しては，手術時に最適な再建方法を選択する方針であったが，最近では不整脈防止の目的で心外導管を選択する傾向となってきている．

おわりに

機能的単心室を有する症例に対しFontan手術を施行した．前期では一期的に右房肺動脈吻合法，Björk法，TCPC手術を行い，後期ではBCPS手術を先行させる段階的TCPC手術を行った．前期と後期を比較すると早期死亡率において改善傾向がみられた．BCPSを介して二期的にFontan手術を施行するstaged repairは有用な手術戦略であると考えた．

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SUMMARY

The Role of Staged Fontan Operation on Early and Long-term Outcome

Yoshimi Iino et al., Division of Cardiovascular Surgery, Keio University School of Medicine, Tokyo, Japan

Of 185 patients with single ventricle physiology, 59 patients who underwent Fontan type operations between April 1970 and May 2002 served as subjects. Subjects displayed a median age of 5.2 years and a median body weight of 11.4 kg. In the first 22 years (group 1), 34 patients underwent concomitant right atrium-pulmonary artery (RA-PA) anastomosis, Björk procedure and total cavopulmonary connection (TCPC), while in the last 8 years (group 2), 25 patients underwent staged TCPC, where bidirectional cavopulmonary shunt (BCPS) and obliteration of additional pulmonary blood flow was performed previously. Four cases of early death (group 1：4 patients, group 2：0 patient) and 12 cases of late death (group 1：11 patients, group 2：1 patient) were encountered. Early mortality was 6.8% (group 1：12%, group 2：0%, $p=0.10$) and late mortality was 21%. The 5-year survival rate was 85.2±4.9% (group 1：80.0±6.8%, group 2：93.8±6.1%, p=NS), and the 10-year survival rate was 79.6±6.0%. Staged TCPC, precedent BCPS with obliteration of additional pulmonary blood flow, seems to be beneficial for accurate patient selection for Fontan candidate.

KEY WORDS：single ventricular physiology/total cavopulmonary connection (TCPC)/bidirectional cavopulmonary shunt (BCPS)

*　　*　　*

The Limitation of Staged Repair in the Surgical Management of Congenital Complex Heart Anomalies with Aortic Arch Obstruction

Objective: Severe aortic arch obstruction including an interrupted aortic arch in congenital complex heart anomalies remains a challenge in surgical management. *Methods:* Treatment and outcomes in 75 consecutive patients who underwent an aortic arch repair as the first step of the staged repair protocol between 1975 and 2000 were reviewed. Their ages at repair ranged from 1 day to 8.5 months. *Results:* Cross-sectional postoperative follow-up data were available in all the patients. The follow-up period ranged from 0 to 27.6 years (mean: 7.3 ± 7.3 years). There were 20 postoperative hospital deaths (27%) and 7 late deaths. The Kaplan-Meier estimate of survival was 81.3% ± 4.5% at 1 month, 68.0% ± 5.4% at 1 year, 65.0% ± 5.5% at 5 years, 63.1% ± 5.7% at 10 years, 63.1% ± 5.7% at 20 years. By Cox regression analysis, body weight of 2.5 kg or less is the only independent determinant of postoperative mortality ($p = 0.04$, multivariable odds ratio: 2.50, [95% confidence interval: 1.02–6.1]). The aortic arch morphology, the primary cardiac lesion, or date of operation did not reach a statistically significant level to show correlation with mortality. Reintervention to reconstruct the aortic arch was performed at 9 occasions in 8 of the 55 patients who survived the primary operation (14.5%). The Kaplan-Meier estimate of the reintervention-free rate was 91.3% ± 4.2% at 5 years, 85.5% ± 5.6% at 10 years, 75.6% ± 8.2% at 20 years. Using multivariable Cox regression analysis, interrupted aortic arch (versus aortic coarctation) was the only independent predictor of a shorter time to reintervention ($p = 0.001$, multivariable odds ratio: 16.1, [95% confidence interval: 3.2–80.2]). *Conclusions:* The staged repair protocol was associated with significant limitations in patient survival and with the development of recurrent aortic arch obstruction. Thus, a primary repair protocol may serve as an alternate approach, especially in patients with low weight or with an interrupted aortic arch. (Jpn J Thorac Cardiovasc Surg 2003; 51: 302–307)

Key words: aortic arch obstruction, staged repair

Ryo Aeba, MD, Toshiyuki Katogi, MD, Kenichi Hashizume, MD, Yoshimi Iino, MD, Kiyoshi Koizumi, MD, Kentaro Hotoda, MD, Shinya Inoue, MD, Hideki Matayoshi, MD, Akihiro Yoshitake, MD, and Ryohei Yozu, MD.

Severe aortic arch obstruction in congenital complex heart anomalies remains a challenge in surgical management. This is in part reflected by the fact that the advantages of primary repair over staged repair have been advocated by several distinguished centers[1-4] but refuted by others.[5-8] For many years, the surgical protocol at the Keio University Hospital was to repair neonates and young infants with severe aortic arch obstruction and cardiac lesions with a staged surgical approach. At the beginning of 2001, the institution switched to a surgical protocol requiring primary repair in patients with biventricular heart. This provided us with a good opportunity to review our 25-year-experience with staged repair.

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Address for reprints: Ryo Aeba, MD, Division of Cardiovascular Surgery, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan.

Subjects and Methods

Between January 1975 and December 2000, there

Table I. *Results of univariable log rank test or Cox regression analysis for factors associated with freedom from postoperative mortality and reintervention for recurrent arch obstruction*

Independent variable	*P value for mortality*	*P value for reintervention*
Chronological case number (continuous)	> 0.1	> 0.1
Age (continuous)	> 0.1	> 0.1
Age < 2 weeks	> 0.1	> 0.1
Weight (continuous)	0.043	> 0.1
Weight < 2.5 kg	0.001	> 0.1
Male sex	> 0.1	> 0.1
Interrupted aortic arch (vs. aortic coarctation)	> 0.1	< 0.00001
Atrial septal defect or single ventricle as associated anomalies	0.051	> 0.1
Repaired by end-to-end anastomosis (vs. subclavian flap aortoplasty)	> 0.1	> 0.1
Repaired by prosthetic tube conduit or patch	> 0.1	0.0002
Pulmonary artery banded	> 0.1	> 0.1
Repaired under temporary shunting	> 0.1	> 0.1

were 75 consecutive patients with congenital heart disease who underwent surgical repair at the Keio University Hospital. They fulfilled the following four inclusion criteria: (1) the presence of congenital heart disease associated with severe aortic arch obstruction; (2) a staged surgical repair; (3) the aortic arch repair was the first operation performed at an age of 12 months or younger; and (4) at the time of the aortic arch repair, other intracardiac anomalies were identified that needed repair in a later second stage operation or spontaneous resolution. Patients with an associated hypoplastic left heart syndrome or total anomalous pulmonary venous connection were excluded from this analysis, because they present with their own unique clinical picture. Inclusion of these patients might have potentially biased the outcome of this study.

There were 40 male and 35 female infants. At the time of the aortic arch repair, they ranged in age from 1 day to 8.5 months (mean: 1.4 ± 1.7 months, median: 20 days) and their body weight ranged from 1.6 to 6.3 kg (mean: 3.2 ± 0.8 kg). The morphology of the aortic arch showed: severe aortic coarctation in 57 patients; interrupted aortic arch with type A in 14 patients; and interrupted aortic arch with type B in 4 patients. The primary cardiac anomaly was found to be: a ventricular septal defect in 53 patients; an atrial septal defect in 8 patients; a single ventricle and its analogue in 7 patients; a complete transposition of the great arteries {S, D, D} or Taussig-Bing anomaly in 4 patients; and Shone's complex in 3 patients.

All the aortic arch reconstructions were performed through a left thoracotomy. The surgical technique used for the aortic arch reconstruction was: resection and end-to-end anastomosis in 35 patients; subclavian flap aortoplasty in 24 patients; and prosthetic patch or tube conduit repair in 16 patients. The choice of the reconstruction technique was largely dependent on aortic arch morphology and the year of the operation. Prosthetic tube grafts were used for the reconstruction of the interrupted aortic arch. In chronological order, aortic coarctation was repaired by prosthetic patch, subclavian flap, or resection and end-to-end anastomosis. Forty-seven patients with absent or mild systemic ventricular outflow tract obstruction were pulmonary-artery-banded according to the guideline advocated by the Toronto group.[9]

Data acquisition and analysis. Preoperative and operative data were collected retrospectively by reviewing patient records and the database of the Congenital Cardiovascular Surgery at The Keio University Hospital. Follow-up information was obtained by contacting the cardiologist and/or family of the patient. Follow-up echocardiographic, surgical, and catheterization-derived data were gathered from the patient records and databases at our institution or from the referring cardiologist if the patient was followed elsewhere.

Data are presented as mean ± standard deviation or median (range), unless otherwise specified. The 2 outcome measures were postoperative mortality and reintervention for recurrent obstruction of the arch. Independent variables assessed for correlation with these outcomes are listed in Table I. Survival and estimates of postoperative freedom from reintervention for recurrent arch obstruction were obtained by the Kaplan-Meier product limit method and are expressed as the mean with 95% confidence intervals. To assess for

independent variables associated with shorter postoperative freedom from intervention, decreased postoperative survival, and aortic arch reintervention, univariable Cox regression analysis was used for continuous variables and log rank test for categorical variables. Variables that were significant at the 0.10 level based on univariable analysis were considered for inclusion in the multivariable Cox regression model. A P value < 0.05 was required for variables to remain in the model. Results of the Cox regression analysis are presented as odds ratio with 95% confidence intervals.

Results

Cross-sectional postoperative follow-up data were available for all the patients. The follow-up period ranged from 0 to 27.6 years (mean: 7.3 ± 7.3 years).

There were 20 postoperative hospital deaths (27%). The causes of death varied. Immediately after the operation, an instability of hemodynamic and/or oxygenation status caused death in 14 patients, 11 of whom had pulmonary artery banding. All these patients had been operated on earlier than 1990. They had a preexisting systemic hypoperfusion with acidosis and renal and/or hepatic dysfunction which was treated with mechanical ventilation and prostaglandin E_1 administration in most cases. These patients died of low output, most often ultimately triggered by tracheal suction. Of the 11 patients who underwent pulmonary banding, 1 underwent reoperation to loosen the pulmonary artery band, but, nevertheless, died of deoxygenation. Of the remaining 6 deaths, 4 infants died of septic complications (such as infective endocarditis, lung abscess, and necrotizing enterocolitis) and 2 died of preexisting infant respiratory distress syndrome with or without pneumothorax.

There were 7 late deaths, occurring from 4 months to 6.3 years postoperatively. Three of these patients died in the early postoperative period following subsequent more definitive operations. Other causes of late death included acute respiratory distress, bronchiolitis, and liver dysfunction with congenital biliary atresia.

The Kaplan-Meier estimate of survival was 81.3% ± 4.5% at 1 month, 68.0% ± 5.4% at 1 year, 65.0% ± 5.5% at 5 years, 63.1% ± 5.7% at 10 years, and 63.1% ± 5.7% at 20 years (mean ± standard error) (Fig. 1). Using Cox regression analysis, body weight of 2.5 kg or less was the only independent determinant of postoperative mortality ($p = 0.04$, multivariable odds ratio: 2.50, [95% confidence interval: 1.02–6.1]). Notably, aortic arch morphology, the primary cardiac lesion, and the date of operation were not statistically significantly correlated

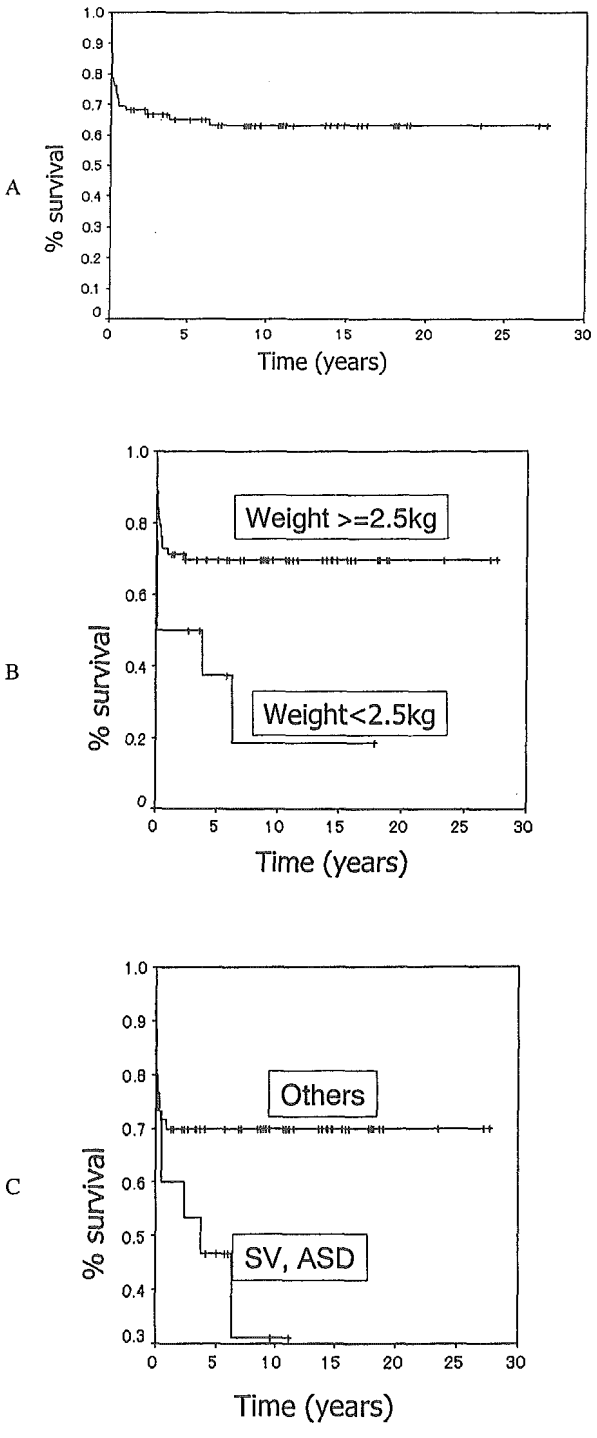

Fig. 1. Kaplan-Meier curves for patient survival after the aortic arch repair
A: all patients
B: stratified according to weight at repair
C: stratified according to the associated anomalies
ASD, Atrial septal defect; *SV*, single ventricle.

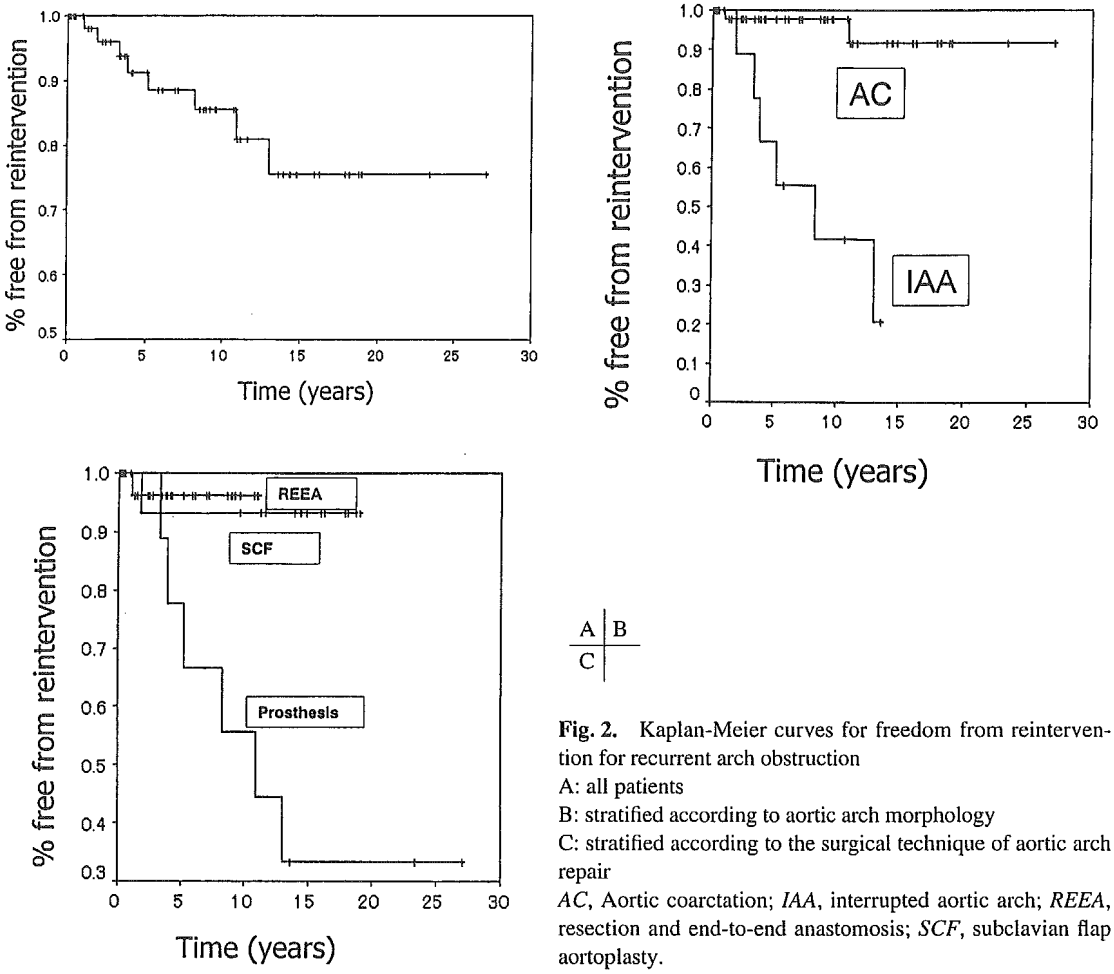

Fig. 2. Kaplan-Meier curves for freedom from reintervention for recurrent arch obstruction
A: all patients
B: stratified according to aortic arch morphology
C: stratified according to the surgical technique of aortic arch repair
AC, Aortic coarctation; *IAA*, interrupted aortic arch; *REEA*, resection and end-to-end anastomosis; *SCF*, subclavian flap aortoplasty.

with mortality.

Reintervention to reconstruct the aortic arch was performed on 9 occasions in 8 of the 55 patients who survived the primary operation (14.5%). Reintervention consisted of: surgically interposing a tube graft in 4 patients (anatomic bypass in 1 patient, and extra-anatomic ascending-to-supra-celiac abdominal aortic bypass[10] in 3 patients); surgical patch aortoplasty in 2 patients; and transcatheter aortoplasty in 3 patients. The Kaplan-Meier estimate of the reintervention-free rate was 91.3% ± 4.2% at 5 years, 85.5% ± 5.6% at 10 years, 75.6% ± 8.2% at 20 years (mean ± standard error) (Fig. 2). Using multivariable Cox regression analysis, an interrupted aortic arch (versus aortic coarctation) was the only independent predictor of a shorter time to reintervention ($p = 0.001$, multivariable odds ratio: 16.1 [95% confidence interval: 3.2–80.2]).

Discussion

Severe aortic arch obstruction with congenital complex heart anomalies in neonates and infants has been traditionally repaired with a staged approach, partly because cardiopulmonary bypass was thought to be intolerably hazardous for such young patients. Recent refinements in surgical technique, including cardiopulmonary bypass equipment such as the bypass circuit and cannula, myocardial preservation, application of modified ultrafiltration, and perioperative management, have contributed to the successful application of a primary repair in neonates and young infants with biventricular cardiac anomalies. One of the most challenging problems in the surgical management of such patients is the establishment of the perfusion cannula position in the usually hypoplastic aorta. During the last decade, attenuation of the complications of circulatory arrest by maintaining regional cerebral flow and

separate perfusion during the aortoplasty procedure has been advocated.[11,12] Thus, many new tools to facilitate primary repair have been recently introduced into clinical practice.

Yet, until recently, or perhaps even today, all or some patients could still benefit from a staged surgical approach. There are certainly some situations in which staged repair is eventually inevitable, such as neonates and young infants with a single ventricle and its analogue, associated hemorrhagic complications, and respiratory syncytial virus infection. Even excluding these situations, opinions on which strategy carries a better outcome vary.[1-8] The answer may depend on several different factors, including the patient's preoperative status, the morphology of the aortic arch and the intracardiac lesions, and the surgical technique used for aortic arch reconstruction. Only prospective randomized studies can answer this important question, although, to the best of our knowledge, none have been completed thus far.

One difficulty for such studies in analyzing this heterogeneous cohort of patients is that many variables used for assessment are continuous in nature. Attempts at categorizing these variables may not adequately describe them. In fact, even the morphology of the aortic arch and of the intracardiac lesions can be seen as falling along a continuum, rather than as fitting into several distinct categories. Furthermore, a review of our data shows that the present study included a wide-ranging heterogeneous patient cohort with severe aortic arch obstruction and major cardiac anomalies. A subset of the aortic coarctations was associated with ventricular septal defects and it was anticipated that these would have the best outcome with a staged repair in this cohort. Yet, even for this small, more homogeneous cohort, there is no consensus as to the best approach, as several authors advocate primary repair[1,2] while others prefer a staged repair.[5-7]

In the present study, lower body weight was an independent risk factor for postoperative mortality. Stratified survival curve shows that this is not only reflected by the higher early postoperative deaths but also by a higher mid-term mortality in those patients who had undergone aortoplasty with a lower body weight at the time of operation. As well, pulmonary artery banding is associated with greater technical difficulty in smaller hearts which have a more narrow range for the adequate tightening of the pulmonary artery band. One can postulate that the inadequate developmental growth of the pulmonary vascular structure in patients with lower weight at the time of arch repair ultimately resulted in poor mid-term survival.

The need for reintervention due to recurrent aortic arch obstruction is another important factor in postoperative outcome. Based on a multivariable analysis, an interrupted aortic arch was the sole independent factor associated with a higher incidence of reintervention. In our series with staged repair, there was a high-grade overlap between this group and the patients who were repaired using a prosthetic tube conduit or patch, which has no growth potential. Since patients in this group are the most likely to have more severe hypoplasia in the ascending and/or transverse arch aorta, tissue-to-tissue anastomosis without residual obstruction under cross-clamping of these vessels is more difficult to achieve. Thus a primary repair would have a definite advantage in these patients, because perfectly non-obstructive arch reconstruction without any prosthesis is much more feasible with technical ease.

The present study reviewed our surgical experience with a staged repair protocol over the last 25 years. The staged repair protocol was associated with significant limitations in patient survival and with the development of recurrent aortic arch obstruction. Thus, a primary repair protocol may serve as an alternate approach, especially in patients with low weight or with an interrupted aortic arch.

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Liberal Use of Tricuspid Valve Detachment for Transatrial Ventricular Septal Defect Closure

Ryo Aeba, MD, Toshiyuki Katogi, MD, Kenichi Hashizume, MD, Kiyoshi Koizumi, MD, Yoshimi Iino, MD, Mitsuharu Mori, MD, and Ryohei Yozu, MD

Division of Cardiovascular Surgery, Keio University, Tokyo, Japan

Background. Although temporary tricuspid valve detachment is useful for improved visualization of ventricular septal defect through right atriotomy, liberal use of this adjunct is not widely supported, mainly because of concerns about iatrogenic complications such as heart blocks and tricuspid valve dysfunction. The objective of this study was to determine whether liberal use of this adjunct can improve operative outcome.

Methods. Between January1997 and March 2002, transatrial closure of isolated ventricular septal defect (conoventricular or canal type) was performed in 87 consecutive patients. Tricuspid valve detachment was used in 4 out of 44 patients (prudent-use group) and 19 out of 43 patients (liberal-use group) in the first and second half of this period, respectively ($p = 0.0002$). Patient demographics and use of other surgical and cardiopulmonary bypass techniques remained virtually unchanged during this period.

Results. In the prudent-use group, there was one operative death with prolonged bypass time and one residual defect that required reoperation; neither of these patients underwent tricuspid valve detachment. All other patients (both groups) were free from mortality and clinically significant complications, including heart block, tricuspid regurgitation, and residual defect. The liberal-use group had shorter cardiopulmonary bypass time than the prudent-use group (59 ± 14 vs 67 ± 22 minutes, $p = 0.037$).

Conclusions. Tricuspid valve detachment should be used liberally for moderate- or even low-difficulty exposure of ventricular septal defect, regardless of patient background, because it is a safe and effective adjunct that can improve speed, programmability, reproducibility, and reliability.

(Ann Thorac Surg 2003;76:1073–7)

Clinical application of temporary tricuspid valve detachment (TVD) for complete visualization of ventricular septal defect (VSD) through right atriotomy is not new. In 1961, Hudsepeth and associates [1] first described this adjunct. Its surgical advantage is obvious, as it allows complete visualization of all margins of the VSD [2–6], helping to minimize the incidence of residual VSD. However, TVD requires additional operative time for incision and repair of the valve apparatus, and carries potential risk of iatrogenic complications such as tricuspid dysfunction and heart blocks.

Questions remain regarding the advantages of TVD in VSD closure, and many surgeons are reluctant to use TVD liberally [4, 7]. Because effects of TVD on surgical outcome are largely affected by the criteria for its use, simple comparison between patients repaired with and without TVD may underestimate these effects. A better way to clarify the role of TVD is to compare different surgical policies regarding indications of TVD, but there have been no reports of such comparisons. At Keio University Hospital, use of TVD has increased during the last 5 years, although patient demographics and use of other surgical and cardiopulmonary bypass techniques have remained virtually unchanged. This allowed us to analyze effects of TVD using a highly homogeneous cohort. The objective of this study was to determine whether liberal use of TVD can improve operative outcome.

Material and Methods

Patients

We retrospectively examined the reports of all consecutive patients operated on at Keio University Hospital between January 1997 and March 2002 who met the following criteria: VSD was the primary cardiac lesion; VSD was either conoventricular or canal type; and VSD was closed through right atriotomy and the tricuspid valve. Criteria for exclusion from this survey were as follows: partial sternotomy access; anatomical type of VSD other than conoventricular or canal type (eg, muscular or conus); multiple VSD; and VSD(s) associated with a more complex cardiac lesion such as tetralogy of Fallot, aortic arch obstruction, transposition of the great arteries, or total anomalous pulmonary venous connection. There were 87 subjects, consisting of 32 (36.8%) male and 55 (63.2%) female patients, and mean follow-up time was 34.0 ± 17.6 months (range, 0.2 to 68.4 months). Median age at operation was 7.9 months (range, 2 to 197 months), and median body weight was 6.2 kg (range, 3.0

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Address reprint requests to Dr Aeba, Division of Cardiovascular Surgery, Keio University, 35 Shinanomachi, Shinjuku, Tokyo 160-8582, Japan; e-mail: aeba@sc.itc.keio.ac.jp.

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Table 1. Liberality in Use of Tricuspid Valve Detachment

Variable	Prudent-Use Group	Liberal-Use Group
n	44	43
Tricuspid valve detachment	4 (9.1%)	19 (44.2%)[a]
Age, median (range)	8.3 (1.7–72) months	7.9 (2.1–197) months
Weight, median (range)	6.3 (3.0–19.7) kg	6.1 (3.1–53.9) kg
Male gender	15 (34.1%)	17 (39.5%)
Down's syndrome	15 (34.1%)	10 (23.3%)
Cardiopulmonary bypass time	67 ± 22 min	59 ± 14 min[b]
Aortic cross-clamp time	35 ± 14 min	33 ± 11 min
Mortality	1 (2.3%)	0 (0%)
Pulmonary arterial hypertension crisis	0 (0%)	1 (2.3%)

[a] $p = 0.0002$; [b] $p = 0.037$.

to 53.9 kg). A total of 25 patients (28.7%) had Down's syndrome.

The use of TVD for better visualization of VSD was at the discretion of the surgeon, but increased experience with TVD and excellent outcomes resulted in general trend towards gradual increase in TVD use in this series. All surgeries were done or supervised by one of the two surgeons. (R.A. or T.K.), and there were no significant intersurgeon differences in frequency in TVD use. The patient cohort was divided into two chronological groups, which represented two different surgical strategies regarding liberality of TVD use (Table 1). The prudent-use group (n = 44) consisted of patients who were operated on before January 2000; TVD was used with low frequency (n = 4, 9.1%). In contrast, the liberal-use group (n = 43) consisted of patients who were operated on after January 2000; TVD was used with higher frequency (n = 19, 44.2%). The difference in use of TVD between these two groups was statistically significant ($p = 0.0002$).

Operative Procedures

Normothermic cardiopulmonary bypass was established after aortic and bicaval cannulation, followed by aortic cross-clamping and delivery of antegrade cardioplegic solution. The right atriotomy was parallel to the atrioventricular groove. A patch of expanded polytetrafluoroethylene patch (Cardiovascular Patch, W. L. Gore and Associates Co, Flagstaff, AZ) was tailored and secured with a running suture technique using a 5-0 or 6-0 double-armed polypropylene suture. For reinforcement, an autologous pericardial strip was attached to the suture at the base of the tricuspid septal leaflet. Modified ultrafiltration was used after termination of cardiopulmonary bypass.

The operative technique of TVD consisted of two separate procedures. In leaflet detachment [1], which was performed in 20 patients, a parallel incision was made in the annulus in the septal leaflet, starting from the inferior aspect and extending to the superior aspect, to avoid incidental injury to the aortic valve adjacent to the anterior-septal commissure of the tricuspid valve. When necessary, this incision was extended to the anterior leaflet beyond the anterior-septal commissure. To minimize mechanical stress from retraction on the atrioventricular node (which could cause blunt tears), the most inferior end was slightly extended toward the 2 O'clock direction, resulting in a hockey-stick-shaped incision in the leaflet (Fig 1). One or two traction suture(s) was passed through the incision to facilitate VSD exposure. After the patch was inserted and secured by this incision, the incision in the leaflet was closed with several simple interrupted or running sutures of 6-0 or 7-0 polypropylene. In chordae detachment [8], which was performed in 3 patients, the major chordae, which were atypically attached to the anterior VSD rim and supported the septal or anterior leaflets, was divided at the end nearest the myocardium. After the patch was secured, the chordae were resuspended to the original site or the patch surface.

Data Acquisition and Statistical Analysis

Medical and surgical records of all patients were reviewed. Follow-up information, regarding current activity level, medications, and perceived complications, was obtained from the consulting physicians or parents of the patient. Postoperative follow-up echocardiography with color-flow mapping was performed for all patients 3 weeks to 6 months after the operation.

Statistical analysis was performed using the SPSS program for Windows (SPSS Inc, Chicago, IL). Quantitative variables with and without normal distribution were expressed as the mean ± the standard deviation of the mean and as the median and range, respectively. Comparison between the two groups for quantitative variables with and without normal distribution was performed using the nonpaired Student's t test and the Mann-Whitney u test, respectively. Differences in categorical variables between the two groups were analyzed using Fisher's exact test. Statistical significance was designated as a p value less than 0.05.

Results

One operative death occurred in the prudent-use group, in a 4-month-old patient without TVD. This patient had Down's syndrome, exhibited severe pulmonary congestion preoperatively, and had a conoventricular-type VSD with canal extension. There were many chordae attached to the VSD rim of this patient, and this interfered with placement of sutures and securing of the patch, resulting in prolonged operative time (aortic cross-clamping time, 66 minutes; cardiopulmonary bypass time, 114 minutes). Postoperative recovery was complicated by low output due to left ventricular dysfunction, and the patient died on the 5th postoperative day.

Another patient with Down's syndrome (5 months old) develòped pulmonary arterial hypertension crisis on the

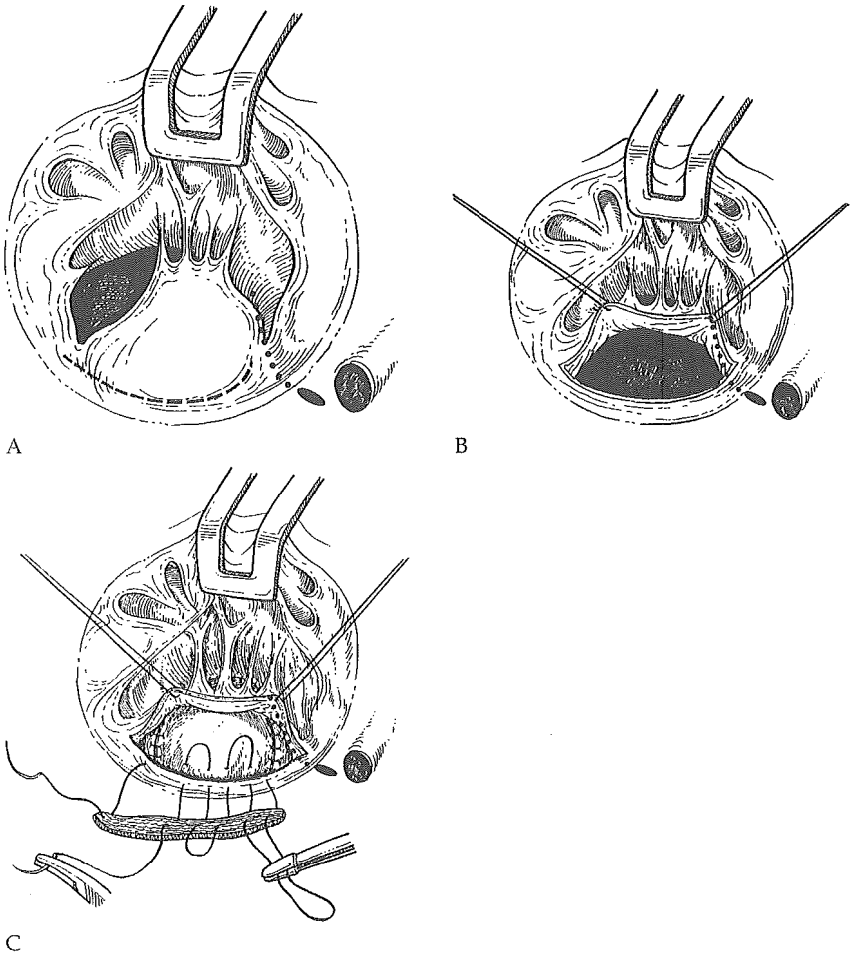

Fig 1. (A) Schematic illustration of tricuspid valve detachment. The leaflet incision was inferiorly extended apart from the annulus. An extension to the anterior leaflet may be used when necessary. (B) One or two traction sutures are used for complete visualization of the ventricular septal defect. (C) The patch is inserted through the leaflet incision, and secured using a running suture technique. An autologous pericardial strip is used for reinforcement of the annulus, followed by leaflet incision repair.

2nd postoperative day. This was successfully treated with nitric oxide inhalation (duration, 7 days).

Cardiopulmonary bypass time was significantly longer for patients with TVD than for patients without TVD (70 ± 21 vs 60 ± 18 minutes, $p = 0.030$); overall mean was 63 ± 19 minutes. Aortic cross-clamp time was also significantly longer for patients with TVD than for patients without TVD (40 ± 14 vs 31 ± 11 minutes, $p = 0.004$); overall mean was 34 ± 13 minutes. However, the liberal-use group had shorter cardiopulmonary bypass time than the prudent-use group, overall (59 ± 14 vs 67 ± 22 minutes, $p = 0.037$) (Table 1), and in both TVD subgroups: patients with TVD, 64 ± 12 versus 101 ± 27 minutes, $p = 0.0002$; patients without TVD, 55 ± 14 versus 64 ± 19 minutes, $p = 0.047$ (Fig 2). Four patients (9.1%) in the prudent-use group had prolonged (> 100 minutes) cardiopulmonary bypass time, whereas no patients in the liberal-use group had prolonged cardiopulmonary bypass time.

No high-degree atrioventricular blocks developed. At follow-up echocardiography (Table 2), tricuspid valve function was not obstructed in any patients. Tricuspid regurgitation was categorized as absent or trivial in 70 patients (80.5%), mild in 16 patients (18.2%), and moderate in 1 patient (1.1%). No patients underwent reoperation to correct tricuspid regurgitation. Residual VSD was either absent or trivial in all but 1 patient (prudent-use group), whose moderate defect was initially repaired without TVD and was reoperated on 14 months later using TVD. At this patient's reoperation, the cranial half of the original defect was largely patent, and was closed using a new patch. There was no significant difference in degree of tricuspid regurgitation or residual VSD between patients with and without TVD.

Comment

Opinions vary among surgeons regarding usefulness of TVD as an adjunctive for transatrial closure of VSD. Consequently, its frequency of use varies widely, from never being used to always being used [4]. TVD allows complete visualization of VSD at the cost of destroying valve architecture, and skepticism involves the balance between this benefit and the potential risks of complications.

There have been several reports suggesting that TVD does not impair tricuspid valve function or increase the risk of heart block [3–5], but there are some differences in surgical details between those studies and the present study. In the present series, an autologous pericardial

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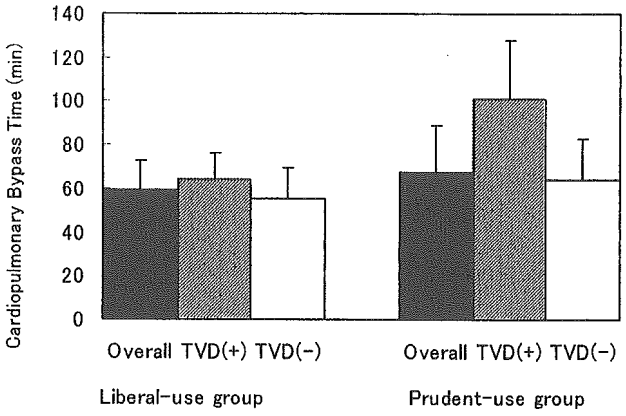

Fig 2. Comparison of cardiopulmonary bypass time between the liberal- and prudent-use groups. Error bar *indicates SD.* TVD(+) = *patient with tricuspid valve detachment;* TVD(-) = *patient without tricuspid valve detachment.* p = *0.037, 0.0002, and 0.047 for overall, TVD(+), and TVD(-) patients, respectively.*

strip was used for reinforcement of the tricuspid septal annulus, regardless of use of TVD, and this may have contributed to preservation of valve competence. Although association of Down's syndrome raises concerns about tricuspid regurgitation after TVD, due to residual systolic hypertension in the right ventricle [3], the present results indicate that TVD does not increase risk of this complication in Down's syndrome patients. An incision completely parallel to the tricuspid annulus may cause atrioventricular node injury, due to mechanical stress or incidental tear with retraction of the incised leaflet. The hockey stick–shaped incision used in the present patients may have helped prevent this serious complication. An incision restricted to the anterior leaflet can help avoid this complication [6], but it carries a risk of incidental injury of the aortic valve or the sinus of Valsalva.

Tricuspid valve detachment requires additional time for incision and resuturing during cardiopulmonary bypass and aortic cross-clamping. Reports indicate that TVD is associated with normal [5] or increased [4] operative time. However, it can be argued that simple comparison of operative times in a cohort between patients with and without TVD is not necessarily meaningful, because the effect of TVD on operative time can be greatly affected by the criteria for its use. In the prudent-use strategy, VSD visualization without TVD is often difficult, and time-saving effects from preservation of the tricuspid valve may be offset or even counterbalanced by the longer time required to close the VSD. It is more meaningful to compare different surgical policies regarding the frequency with which TVD is used. To the best of our knowledge, the present study is the first in which this approach has been used. In the present study, the liberal-use strategy actually made clinically crucial operative times more short than long in the aggregate despite a short-time consumptive nature of TVD procedure itself. No patients in the liberal-use group had an aortic cross-clamping time exceeding 60 minutes. This implies that liberal use of TVD can improve programmability, reproducibility, and reliability of VSD closure. This is beneficial, especially for patients with severely ill preoperative status.

Table 2. Follow-Up Echocardiography

	TVD (+) (n = 23)	TVD(−) (n = 64)	*p*
Tricuspid stenosis			>0.1
None	23 (100.0%)	64 (100.0%)	
Tricuspid regurgitation			>0.1
None/trivial	15 (65.2%)	55 (86.0%)	
Mild	8 (34.8%)	8 (12.5%)	
Moderate	0 (0%)	1 (1.6%)	
Massive	0 (0%)	0 (0%)	
Residual VSD			>0.1
None/trivial	23 (100.0%)	63 (98.1%)	
Mild	0 (0%)	0 (0%)	
Moderate	0 (0%)	1 (1.6%)[a]	
Massive	0 (0%)	0 (0%)	

[a] Reoperated.

TVD = tricuspid valve detachment; VSD = ventricular septal defect.

More importantly, nonuse of TVD may result in incomplete visualization and incomplete closure of the VSD, or excessive traction of the tricuspid valve apparatus in an effort to optimize visualization, leading to tricuspid regurgitation or heart blocks. Whereas not statistically significant, the present finding that the only patient who underwent reoperation for residual VSD was in the prudent-use group and underwent initial repair without TVD is consistent with the findings of Gaynor and associates [5].

The present study has some limitations. The first concern is study design. TVD is not necessary in all patients undergoing transatrial VSD closure. The cut-off point for use of TVD has not been clearly quantitatively determined, and liberality of TVD use is defined only by frequency of use. Consequently, it is not feasible to conduct a prospective randomized comparison study of two different surgical policies regarding liberality of TVD use. Thus, the present study is necessarily a historical comparison, which carries a potential bias. However, other than the increased frequency of TVD, use of surgical and cardiopulmonary bypass techniques remained virtually unchanged during the study period, and we believe this contributes to the reliability of the present results. Second, the present study lacks long-term follow-up, especially for growth and competence of the tricuspid valve. Bol-Raap and associates [4] reported that, after TVD, echocardiography showed the tricuspid valve to be completely or almost completely competent, both immediately after repair and an average of 2.0 years after repair. This suggests that, in the present series, tricuspid valve function will remain satisfactory and uncomplicated in the long term, but follow-up is mandatory.

We conclude that TVD should be liberally used for moderate- and even low-difficulty VSD exposure, regardless of preoperative clinical status, age, patient size, or

presence of Down's syndrome. TVD can improve speed, programmability, reproducibility, and reliability of VSD closure, without iatrogenic complications.

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Apico-Pulmonary Artery Conduit Repair of Congenitally Corrected Transposition of the Great Arteries With Ventricular Septal Defect and Pulmonary Outflow Tract Obstruction: A 10-Year Follow-Up

Ryo Aeba, MD, Toshiyuki Katogi, MD, Kiyoshi Koizumi, MD, Yoshimi Iino, MD, Mitsuharu Mori, MD, and Ryohei Yozu, MD

Division of Cardiovascular Surgery, Keio University, Tokyo, Japan

Background. In conventional repair of the congenitally corrected transpositions of the great arteries associated with ventricular septal defect and pulmonary outflow tract obstruction, the placement of the left ventricle–pulmonary artery conduit is at risk owing to probable compression by the sternum, heart block, or injury to the mitral anterior papillary muscle. Apical placement of the left ventriculotomy for the inflow conduit rather than in the midportion or base placement may avoid these complications, although this results in a long and winding extracardiac conduit that may be short-lived because of the proliferation of pseudointima.

Methods. Between 1985 and 1990, a nonvalved Dacron woven-fabric graft conduit was placed between the left ventricular apex and pulmonary artery in 5 patients (mean age, 6.2 ± 1.7 years) who were then followed for at least 10 years.

Results. No iatrogenic heart blocks or mitral regurgitation developed. All patients were complaint-free during the follow-up period, although 1 patient who was clinically well died suddenly in the 10th follow-up year. Cardiac catheterization in the 10th follow-up year indicated a pressure gradient of 21 ± 6 mm Hg across the conduit, and angiography revealed that the conduit diameter was 91% ± 6% of the original conduit diameter.

Conclusions. The reportedly poor early and late outcomes that occur after a conventional repair of congenitally corrected transpositions of the great arteries associated with ventricular septal defect and pulmonary outflow tract obstruction, which places an extracardiac conduit between the left ventricle and the pulmonary artery, may be partially neutralized by relocating the inflow position to the apex.

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Congenitally corrected transposition of the great arteries (CCTGA) with a ventricular septal defect (VSD) and pulmonary outflow obstruction (POTO) remains a surgical challenge. Although there is agreement that CCTGA-VSD is best treated by an anatomic repair (atrial baffle plus arterial switch operation), the merits of the three current surgical options for CCTGA-VSD-POTO are debatable. These three options include: (1) conventional repair with extracardiac conduit repair (Rastelli operation) or pulmonary arterio-ventriculoplasty; (2) anatomic repair (atrial baffle plus Rastelli operation); and (3) the Fontan operation. The long-term outcome after conventional repair, in which morphologic right ventricle is used as the systemic ventricle, is suboptimal because of a high incidence of tricuspid regurgitation, complete atrioventricular block, and progressive right ventricular dysfunction [1–3]. On the other hand, the theoretical advantage of an anatomic repair, in which morphologic left ventricle is used as the systemic ventricle, is appealing. The early outcome is encouraging despite the technical complexity and challenge of the procedure [4, 5]. However, this anatomic repair approach can be contraindicated or unfavorable in a variety of difficult situations, which include the existence of a small-sized thorax, dextrocardia, severe supraventricular tachyarrhythmia, mitral valve regurgitation, mitral chordae malinsertion, and left ventricular myocardial dysfunction. Another concern includes long-term complications inherent in atrial baffle and extracardiac conduit. Although a modified Fontan procedure is an alternative procedure of choice, it has several well-known long-term problems. Therefore, conventional repair continues to play an important role even in the current era. In conventional repair, a morphologic left ventricle to pulmonary artery continuity is most often established by placing an extracardiac conduit. The {S,L,L} segmental anatomy represents this anomaly, for which placement of the inflow of the conduit somewhere in the left ventricular anterior wall has been advocated [6–10]. The usual placement of the left ventricle–

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Address reprint requests to Dr Aeba, Division of Cardiovascular Surgery, Keio University, 35 Shinanomachi, Shinjuku, Tokyo 160-8582, Japan; e-mail: aeba@sc.itc.keio.ac.jp.

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pulmonary artery conduit results in a risk of conduit and coronary artery compression by the sternum, heart block, or injury to the mitral anterior papillary muscle. We hypothesized that an apical placement of the left ventriculotomy for the inflow of the conduit rather than the midportion or base could avoid these complications. However, this approach results in a long and winding extracardiac conduit that may be short-lived as a result of the proliferation of pseudointima. In the present study, we evaluated the effects of this modification by analyzing the data of 5 patients who underwent apico-pulmonary arterial conduit repair and were followed for at least 10 years.

Patients and Methods

Between July 1985 and January1990, there were 5 consecutive patients (4 boys, 1 girl) with CCTGA-VSD-POTO who underwent a surgical repair using an extracardiac nonvalved left ventricular apex to pulmonary artery conduit at the Keio University Hospital, and who were then followed for 10 years or longer after the operation (Table 1). At the time of operation, the patients ranged in age from 4 to 8 years (mean, 6.2 ± 1.7 years). The body weight at operation ranged from 15.7 to 20.9 kg (mean, 18.5 ± 2.2 kg). One of the patients had previously undergone a modified right Blalock-Taussig shunt 6 years before the operation. All patients had situs solitus of the atrial and abdominal viscera with {S,L,L} segmental anatomy. Two patients had levocardia, 2 patients had dextrocardia, and 1 patient had mesocardia. There were 2 other patients with CCTGA-VSD-POTO who underwent other operations during the same time frame, and they are excluded from the present series. One patient with hypoplastic pulmonary artery and systemic right ventricle was managed by placement of a systemic-to-pulmonary shunt, and the other patient underwent a pulmonary outflow tract reconstruction with a spiral patch plus VSD closure [11].

Preoperative cardiac evaluation included echocardiography and cardiac catheterization. All patients had a normal sinus rhythm. Echocardiographic measurement showed two ventricles and atrioventricular valves with a well-balanced dimension. All patients had cyanosis and arterial oxygen saturation with room air ventilation ranging from 84% to 90%, with a mean of 86% ± 3%. The end-diastolic pressure of the left ventricle ranged from 3 mm Hg to 9 mm Hg, with a mean of 5.6 ± 2.8 mm Hg.

All operations were performed through a midline sternotomy with cardiopulmonary bypass, moderate systemic hypothermia, and cardioplegic heart arrest. All of the VSDs were single and large, located at an inlet position (adjacent to the tricuspid and mitral valves), and committed to the pulmonary valve, which was obstructive. Closure of the VSD was performed through the right atriotomy and mitral valve. An equine pericardial patch was tailored and secured with interrupted polyethylene terephthalate fiber (Dacron) -pledgetted horizontal mattress sutures. At the anterosuperior half of the VSD margin, the stitches were placed through the VSD itself and on the right ventricular side of the VSD crest, as suggested by de Leval and colleagues [12].

Table 1. Patient Characteristics

Patient No.	Age at Operation (y)	Weight at Operation (kg)	Sex	Cardiac Anatomy	Previous Operation	Conduit Size (mm)	Complications	Right Ventricular Wall Motion	Tricuspid Regurgitation	Left Ventricular Wall Motion	Mitral Regurgitation	Outcome
1	7	20.5	M	{S,L,L}, levocardia	None	18	None	Normal	Mild	Normal	Mild	Alive and asymptomatic
2	6	17.2	F	{S,L,L}, dextrocardia	None	20	None	Mildly depressed	Moderate	Normal	None	Alive and asymptomatic
3	4	18.0	M	{S,L,L}, mesocardia	None	18	Temporary AV block	Moderately depressed	Prosthetic valve	Normal	None	Tricuspid valve replacement (1.8 y), sudden death (10 y)
4	8	20.9	M	{S,L,L}, levocardia	Blalock-Taussig shunt	22	Cerebral infarction (2 yr)	Normal	Moderate	Normal	Mild	Alive and asymptomatic
5	4	15.7	M	{S,L,L}, dextrocardia	None	20	None	Normal	Trivial	Normal	Trivial	Alive and asymptomatic

AV = atrioventricular.

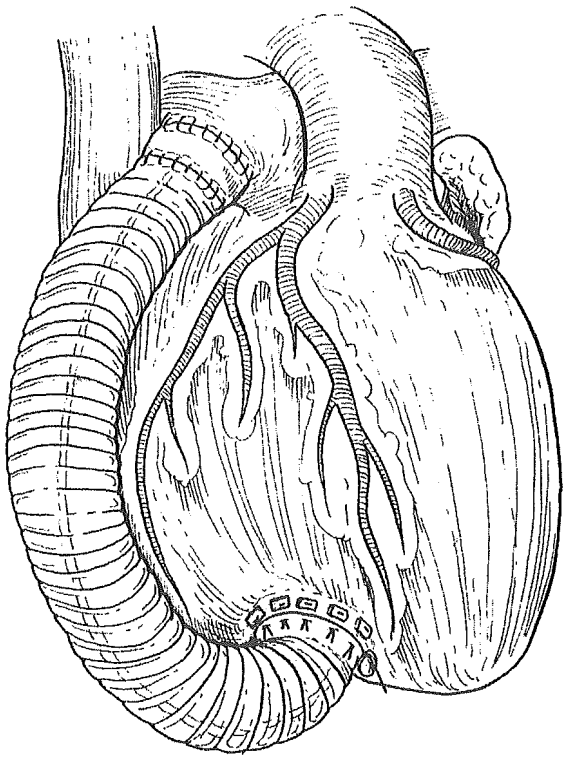


Fig 1. Intraoperative illustration showing the long and winding extracardiac conduit starting at the morphologic left ventricular apex and ending at the pulmonary trunk.

The exact attachment of the mitral anterior papillary muscle was identified in the midportion of the anterior free wall by digital manipulation from inside, and a left ventriculotomy was created in the apex to serve as the inflow of the extracardiac conduit. The pulmonary trunk was opened, and the hypoplastic pulmonary valve was either left open or a primary suture-closure was done. A nonvalved Dacron woven fabric graft conduit (Cooley Veri-Soft Vascular Graft; Meadox Medicals, Inc, Oakland, NJ) with a diameter of between 18 and 22 mm was tailored and placed between the left ventricular apex and the pulmonary artery (Fig 1). An interrupted pledgetted mattress suture technique was used for the proximal anastomosis, and an equine pericardial cuff was placed to reinforce the distal anastomosis. The conduit was placed between the right atrium and lateral pericardium, and was separate from the sternum along its entire course. A permanent pacemaker lead was placed in 2 patients for potential future use, but no generators were connected.

The cardiopulmonary bypass time ranged from 132 to 201 minutes, with a mean of 159 ± 33 minutes, and the aortic cross-clamp time ranged from 79 to 140 minutes, with a mean of 96 ± 25 minutes.

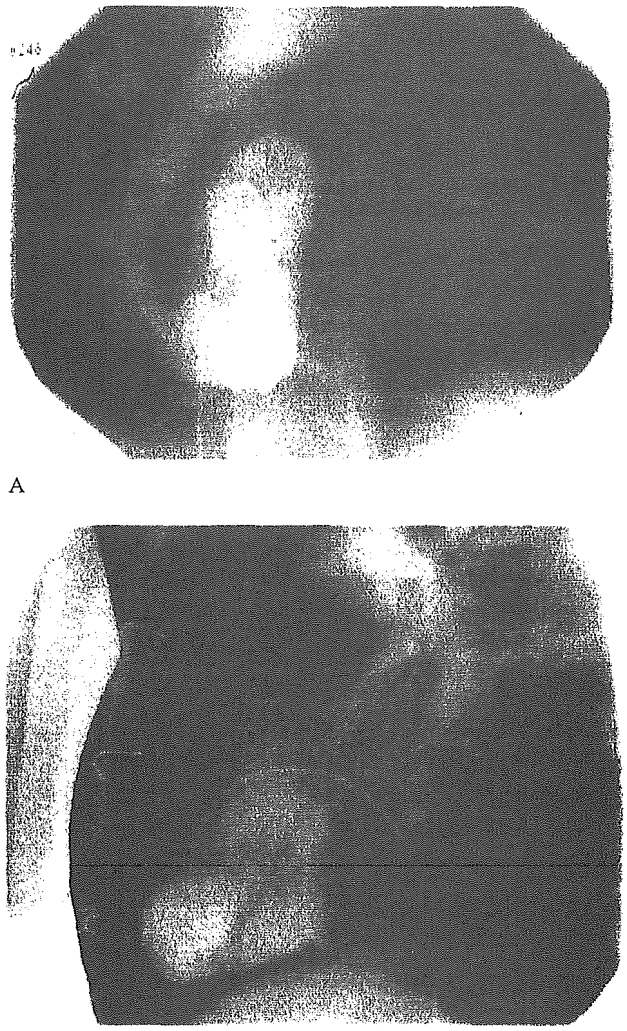
All the data were obtained from retrospective review of patients' hospital and clinical records preoperatively and postoperatively. The ventricular wall motions and the atrioventricular valve competence were assessed from serial echocardiography and the cineangiograms. Late follow-up cardiac catheterization was performed in all patients, with 4 patients catheterized in the 10th follow-up year and 1 patient (patient no. 3) catheterized in the third year. Data are presented as range and mean with standard deviation.

Results

The early postoperative recovery was generally uneventful in all patients, and there were no hospital deaths. All patients maintained a normal sinus rhythm postoperatively although 1 patient showed temporary complete atrioventricular block that was treated with a temporary pacemaker and spontaneously resolved on the 10th postoperative day. Predischarge echocardiography showed moderate tricuspid regurgitation in 3 patients, and no patients were found to have moderate or more severe mitral regurgitation.

All patients were generally complaint-free during the follow-up period. However, 1 patient (No. 4) had a minor cerebral infarction in the left middle cerebral arterial region in the second year. Another patient (No.3) who was complaint-free showed moderately depressed right ventricular wall motion with moderate tricuspid regurgitation, and therefore underwent a tricuspid valve replacement within 1.8 years of the primary repair. Thereafter, this patient's course was uneventful, but he died suddenly in the 10th follow-up year.

The latest available chest roentgenogram showed that cardiothoracic ratio remained within the normal range (47.7% to 55.1%; mean, 49.8% ± 3.5%). On the latest echocardiographic evaluation the right ventricular wall motion was assessed as normal in 3 patients, mildly depressed in 1 patient, and moderately depressed in 1 patient. Tricuspid valve regurgitation was moderate in 2 patients, and mild or trivial in 2 patients (1 tricuspid valve was replaced). Of note, left ventricular wall motion was not depressed, and mitral valve regurgitation did not develop in any of the patients. No significant deterioration of the ventricular wall motion and atrioventricular valve regurgitation was observed in the follow-up period. At follow-up catheterization, the right ventricular end-diastolic pressure ranged from 4 to 11 mm Hg, with a mean of 6.8 ± 3.1 mm Hg, and the left ventricular end-diastolic pressure ranged from 3 to 10 mm Hg, with a mean of 6.5 ± 2.9 mm Hg. The peak systolic pressure gradient across the extracardiac conduit ranged from 14 to 29 mm Hg, with a mean of 21.2 ± 5.6 mm Hg, and angiography revealed the conduit diameter to be 91% ± 6% of the original conduit diameter (Fig 2). The conduit flow was nonturbulent, and pulmonary regurgitation flow was minimal in all patients. There were no patients with increased end-diastolic or end-systolic volume in the right or left ventricle that exceeded 150% of normal value for age. Other than patient 3, no reoperations were required for any reason such as conduit restenosis, tricuspid or mitral valve regurgitation, or residual VSD. Three patients (Nos. 1, 4, and 5) underwent exercise performance examinations, which showed 100% functional aerobic capacity, with a maximum oxygen uptake of from 35.8 to 52.6 $mL \cdot kg^{-1} \cdot min^{-1}$.



A

B

Fig 2. A morphologic left ventriculography performed 10 years after the conduit repair, showing the unobstructed conduit. Note that the conduit is separate from the sternum along its entire course. (A) Frontal view. (B) Lateral view.

Comment

The extracardiac conduit repair of this rare anomaly usually involves a conduit inflow that has been placed somewhere in the anterior wall of the left ventricle, with the exact placement depending on the particular situations [6–10]. The actual location may be chosen based in part on surgical intuition that an extracardiac conduit should be as short and straight as possible. However, there are several concerns with an extracardiac conduit that rests on the anterior wall. First, this conduit is most often positioned underneath the sternum, and therefore the conduit and the left circumflex coronary artery are at risk of being subjected to compression. Second, there is a concern about an increased risk of incidental cavity entry during the time of future, and in many cases inevitable, conduit replacement. Third, owing to the more sagittal position of the ventricular septum [13], the anterior papillary muscle is at risk of direct injury, deviation, or ischemia as a result of coronary supply interruption by a left ventriculotomy, and the space-occupying effect of the conduit. The resultant right-sided atrioventricular valve regurgitation may be detrimental because the morphologic left ventricle can poorly tolerate acute physiologic overload volume [14], especially when pulmonary vascular resistance is marginally high or the left ventricular volume is marginally low. Moreover, the left ventricular wall motion may be restricted with a tethering by the conduit inflow. The impaired performance of the pulmonary ventricular function as a result of these detrimental effects may, in fact, explain suboptimal early survival after conduit repair. Fourth, the procedure has a risk of a surgically created complete heart block, the incidence of which should be minimized because it is generally not well tolerated by patients with this anomaly [14]. Unfortunately, this complication, although less common, continues to be problematic even with the use of refined surgical technique to protect the conduction bundle [12]. The actual placement of the conduit near the conduction bundle, which passes the anterior margin of the VSD, may increase the risk of atrioventricular block because of the mechanical force (traction or compression) created by insertion of the conduit. Therefore, an apicostomy may be advantageous.

Left ventriculotomy done at the apex for an apicoaortic valved conduit has been used to relieve aortic stenosis in hearts with normal atrioventricular and ventriculoarterial alignment. Successful clinical results after such apicostomy [15] substantiate the advantage of a minimally sacrificed ventricular function that this approach offers. However, one can argue that the functional impact of an apicostomy in the CCTGA-VSD-POTO heart may be different from relatively normal heart.

In all patients of this series, mitral valve function was well maintained. Currently, a conventional repair is often indicated for patients with a preexisting abnormal mitral valve [16, 17] inasmuch as this represents a contraindication for an anatomic repair approach. In such circumstances, a left ventriculotomy on the apex rather than in the anterior free wall may be of particular benefit, because it should not lead to a deterioration of the preexisting abnormal mitral valve function, which could be potentially fatal. With regard to development of tricuspid valve regurgitation, our outcome is essentially parallel to previous reports after conventional repair [1–3]. Because tricuspid valve regurgitation is closely interlinked with right ventricular dysfunction and complete heart block [18, 19], an aggressive approach for tricuspid valve regurgitation or the prophylactic placement of a permanent pacemaker may play a beneficial role in dealing with the concern about long-term right ventricular function.

Despite these potential advantages of our approach, we were initially concerned about the fate of the conduit. By necessity, the conduit is longer and more winding than others, and intuitively one can suppose that the conduit may be short-lived owing to the proliferation of pseudointima rather than being outgrown, because the conduit size ranged from 18 to 22 mm and therefore was probably large enough to last into adulthood. Our surgical experience with nonvalved Dacron conduit repair in more conventional outflow tract positions is composed of 20 procedures, of which 6 conduits were replaced between 8 and 12.5 years after the operation, and is at least similar to one with this anomaly. The encouraging long-

term result of the conduit in this series may warrant reconsideration of the surgical intuition on which the current clinical approach is based.

Several new surgical options have been advocated since the patients in this series were operated on, and patient selection for this operation at this moment is debatable. Anatomic repair is the procedure of choice in cases without unfavorable circumstances as discussed earlier. Even in conventional repair, a patch reconstruction of pulmonary outflow tract reconstruction is an attractive option if the anatomy of the pulmonary valve annulus and left circumflex coronary artery is suitable for it. The indication of conventional conduit repair may be therefore limited in highly selected patients.

In conclusion, the reportedly poor early and late outcomes that occur after the conventional repair of CCTGA-VSD-POTO with placement of an extracardiac conduit between the left ventricle and the pulmonary artery may be partially neutralized by relocating the inflow position to the apex. This encouraging outcome may warrant the continuation of conventional conduit repair with our modification in selected patients rather than attempting to perform an anatomic repair or a modified Fontan procedure.

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DISCUSSION

DR MARSHALL L. JACOBS (Philadelphia, PA): That is a very, very nice presentation of an interesting patient group with long-term follow-up after a very elegant operation.

Ryo, there are several things that strike me before one even gets to the anatomic substrate of congenitally corrected transposition. Long-term patency and durability of crimped Dacron conduits between a subpulmonary ventricle and pulmonary arteries with only 9% reduction in the luminal diameter is quite atypical, and I do not know whether it is related to patient age or to some other factor that you might comment on.

Second, of course, of interest is the 100% aerobic capacity and the excellent exercise performance of patients with a nonvalved conduit between the subpulmonary ventricle and the pulmonary arteries at this long-term follow-up. I wonder if there are other instances where you and your colleagues by choice use nonvalved conduits between the subpulmonary ventricle and pulmonary arteries.

And finally, with this very nice cohort from 1985 to 1990, are you continuing to do this operation or would similar patients in the current era be managed by an atrial inversion and a Rastelli type conduit repair?

DR AEBA: Thank you, Dr Jacobs. Actually, in terms of the first question, I do not have any good explanations regarding why our patients had such good pressure gradient between the left ventricle and the pulmonary artery. However, all conduit are

separated from the sternum or any bone structures along its entire course, which is unusual for the other anomalies.

DR JACOBS: No turbulence from compression to create a nidus. . . .

DR AEBA: I think so. The completely round shape of the conduit's cross-section may be good.

DR JACOBS: The second question was just about the general utility of nonvalved subpulmonary conduits.

DR AEBA: With regard to the second question it was 10 years ago or even more when these patients were operated on. At that time in my country no homograft was available whatsoever. So our policy was we did not put any valves in a conduit unless it was absolutely necessary, but in the current era we have much greater availability of more sophisticated and new-generation valves, so I would put the valves in the conduit for selected patients.

DR JACOBS: Many of these patients might have required earlier reoperations if a homograft valve had been incorporated into the Dacron conduit.

DR AEBA: Yes. But if you compare it with 10 years ago, we have a much better valved conduit.

DR JACOBS: And what would be your current approach to these patients?

DR AEBA: It depends on the conditions of the associated lesions as discussed in the slides. If I would have a patient with preexisting mitral problems, or preexisting supraventricular tachyarrhythmia, and so forth, I wouldn't do the anatomic repair, which means an atrial baffle plus a left-sided right ventricle-to-pulmonary artery repair. So it depends on the other conditions.

DR ALEX PALACIOS (Mexico City, Mexico): What do you think about the technique of enlarging the outflow tract through the atrioventricular (AV) groove, close to the AV groove, only with a patch, and have you had any experience with this technique?

DR AEBA: I am sorry, I did not understand your point.

DR PALACIOS: The technique of enlarging the outflow tract only by cutting through the AV groove, close to the AV groove, and enlarging it with a patch that was described just a few months. . . .

DR JACOBS: Direct assault on the subpulmonary obstruction through the AV groove, which is a new alternative to extracardiac conduit repair.

DR AEBA: In selected patients we can do that, but I think a significant number of the patients cannot undergo this kind of a newer technique, for example, a narrow region for the ventricular outflow tract. So in such cases we still need these kinds of operations.

DR TOM R. KARL (San Francisco, CA): I thought that was a fantastic presentation. You know, it seems the more we discuss this disease, the less we understand it, and one would not have predicted that the results with this approach would be so good. So I wonder, is the good late hemodynamic result of a nonvalved conduit partly because it is attached to a left rather than a right ventricle, or is it because of the extreme length of the conduit that naturally limits some of the insufficiency, or do you have other explanations?

Second, could you say again exactly how you decide on the best site for the ventriculotomy and the proxima attachment of the conduit, which seems to be the key point in your technique.

DR AEBA: Thank you.

I would like to answer the second question first. Before I determine the ventriculotomy site, I use digital manipulation. We should identify the attachment of the mitral anterior papillary muscle and then we can avoid the ventriculotomy site far away from the attachment of the papillary muscle. Eventually we incise the real apex in the left ventricle, where I believe it is quite unusual for the attachment of the papillary muscle or other dangerous structure.

The first question is related to the. . . .

DR JACOBS: The first question was related to the excellent performance of the nonvalved conduit, and Dr Karl speculated whether the length had some effect on limiting regurgitation.

DR AEBA: Initially we thought that this type of conduit may be short-lived, which is kind of surgical intuition. Surprisingly enough, our data did not support my surgical intuition. So our point is, in terms of the longevity of the extracardiac conduit, the longevity might have nothing to do with its length or curvature.

DR JACOBS: Ryo, does the left ventricular apical attachment of the conduit involve any stent or sewing ring, or is it simply a running anastomosis to the epicardium?

DR AEBA: Actually no particular device. Just pledgeted horizontal mattress sutures were placed.

DR PEDRO J. DEL NIDO (Boston, MA): One of the things I found quite remarkable about your presentation is that in the end, you still have a systemic right ventricle, and what was most impressive, is the finding that the patients that you did exercise testing on had normal exercise capacity. I found this quite surprising, and one would not predict it. Could the findings of exercise testing be age related, because if you evaluate 15- or 20-year-old patients who had a Mustard procedure, they have reasonably well-preserved exercise capacity. If you look at 25- to 30-year-old patients who have had just a Mustard, they have markedly diminished exercise capacity. So could your findings simply be that at the time you study them, they are still relatively young?

DR AEBA: Yes, that is a good point, Dr Del Nido. It will be our greatest concern, you know, maybe only after 20 or 30 years later. Even in the isolated congenitally corrected transposition with no ventricular septal defect or no pulmonary stenosis, its natural history is similar to the patient after the Mustard repair. However, anatomic repair has also the different kinds of long-term problems, and ventriculo- arterioplasty may be often associated with need for a bidirectional Glenn shunt which causes the chronic pulmonary arteriovenous fistula. So I think it compares different kinds of long-term problems.

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Computational Fluid Dynamics Analysis of an Intra-Cardiac Axial Flow Pump

*Ayumi Mitoh, †Tetsuya Yano, †Kazumitsu Sekine, †Yoshinori Mitamura, ‡Eiji Okamoto, §Dong-Wook Kim, #Ryohei Yozu, and #Shiaki Kawada

**Tomakomai National College of Technology, Tomakomai; †Hokkaido University Graduate School of Engineering, Sapporo; and ‡Hokkaido Tokai University School of Engineering, Sapporo, Japan; §Soonchunhyang University, Asan, Korea; and #School of Medicine, Keio University, Tokyo, Japan*

Abstract: A low rate of hemolysis is an important factor for the development of a rotary blood pump. It is, however, difficult to identify the areas where hemolysis occurs. Computational fluid dynamics (CFD) analysis enables the engineer to predict hemolysis on a computer. In this study, fluid dynamics throughout intracardiac axial flow pumps with different designs were analyzed three-dimensionally using CFD software. The computed pressure-flow characteristics of the pump were in good agreement with the measurements. The Reynolds shear stress was computed along particle trace lines. Hemolysis was estimated on the basis of shear stress (τ) and its exposure time (Δt): $dHb/Hb = 3.62 \times 10^{-7} \tau_i^{2.416} \times \Delta t_i^{0.785}$. Particle damage increased with time along the particle trace lines. Hemolysis of each of the pumps was measured in vitro. The computed hemolysis values were in good agreement with the experimental results. CFD is a useful tool for developing a rotary blood pump. **Key Words:** Axial flow blood pump—Computational fluid dynamics—Hemolysis.

Cardiovascular assist devices have been used for recovery of a failing natural heart or as a bridge to transplantation. Various assist devices have been developed. Pulsatile and nonpulsatile blood pumps each have their own characteristics. A pulsatile pump has a flow waveform similar to that of the natural heart, and has been used for long-term support. However, a pulsatile pump is large and is difficult to implant in small people. In addition to the size problem, mechanical reliability may be a problem due to the complicated structure for generating a pulsatile flow. On the other hand, a nonpulsatile pump has a simple structure and is smaller than a pulsatile blood pump. These characteristics make a nonpulsatile pump suitable for implantation in small people. Although the feasibility of long-term nonpulsatile flow circulation has not been verified, several axial flow pumps have been used clinically (1). An axial flow blood pump can be made smaller than a centrifugal blood pump because of its higher specific speed. However, the possible effects of the high-speed impellers used in axial blood pumps on blood damage should be considered. Hemolysis occurs in areas of high shear stress and eddy. A pump should be designed to avoid these areas. These areas of high shear stress and eddy in the pump must be identified in order to improve pump design. However, evaluations of pump performance and hemolysis both in vitro and in vivo require a long time and are costly. Moreover, animal experiments have been reduced in recent years due to considerations of animal welfare. Evaluation of the performance and hemolysis of a blood pump by a numerical technique is therefore preferable (2). There are several CFD analyses of various types of blood pumps aimed at studying the relationship between the flow structure and hemolysis in vitro (2,3). Several investigators have designed rotary blood pumps, both axial and centrifugal, based on results of computational fluid dynamics (CFD) (4–7).

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Address correspondence and reprint requests to Dr. Ayumi Mitoh, Department of Mechanical Engineering, Tomakomai National College of Technology, 443 Nishikioka, Tomakomai, Hokkaido 059-1275, Japan. E-mail: amitoh@me.tomakomai-ct.ac.jp