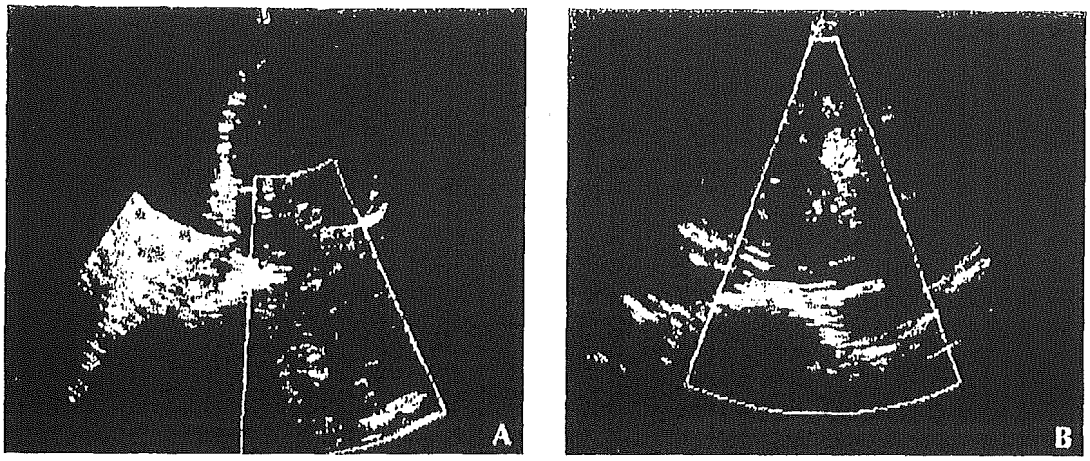

Figure 1. *Echocardiography demonstrated grade 4 mitral regurgitation due to posterior leaflet prolapse.* (A) Long axis view. (B) Short axis view.

Figure 2. From the surgeon s view, remarkably dilated annulus and torn chorda of the middle scallop of the posterior leaflet with dysplasia of the posteromedial commissural scallop were seen.

Postoperative echocardiography revealed mild mitral regurgitation. However, no progression of mitral regurgitation was observed at 1 year follow-up. Sinus rhythm was maintained successfully without anti-arrhythmic drugs and the use of a mechanical valve and anticoagulation therapy was avoided.

DISCUSSION

EDS is a connective tissue disorder characterized by hyperextensibility of the skin, joint hypermobility, fragility of the blood vessels, and increased susceptibility to bleeding. It was reported that type IV EDS results from mutations in the gene for type III procollagen,[1] however, the molecular defect of the common type of EDS has not been identified as yet.[3] Cardiovascular abnormalities are also typical manifestations of EDS and may affect the life span.[2]

In mitral regurgitation reconstruction of the valve is considered the procedure of choice, even for patients with an underlying progressive connective tissue disorder. In Marfan's syndrome, greater understanding of the complicated anatomy of valvular and subvalvular structures has improved the quality of mitral valve repair. It has been widely accepted that the early and intermediate-term durability in Marfan's syndrome was similar to that of non-Marfan degenerative mitral valve disease. Fuzellier and colleagues reported that freedom from mitral valve re-operation was 87.1% at 10 years,[4] while Gillinov and coworkers reported that the actuarial freedom from significant regurgitation was 88.3% at 5 years.[5] In patients with EDS, no detailed anatomical characteristics of valve structures peculiar to this syndrome have been delineated as yet. Since there are only a few reports of mitral valve surgery in patients with EDS, the durability of the repaired mitral valve remains unclear.[6,7]

In the present case, mitral regurgitation was due to a torn chorda with severe myxomatous degeneration. Regurgitation could be effectively reduced by quadrangular resection of the prolapsing part of the posterior leaflet. The pathological examination of the surgical specimen revealed disruption of the fibrous structure in the leaflet and chordal tissue similar to that seen in patients with degenerative mitral regurgitation.[4] Elimination of atrial fibrillation is also essential to avoid anticoagulation therapy. To facilitate the recovery of sinus rhythm, we performed a modified Maze procedure. Our current modified Maze procedure, previously reported in detail,[8] consists of pulmonary venous isolation and interruption of atrial conduction using cryo-ablation through a standard right-sided left atriotomy. The cryo-Maze procedure requires less than 30 minutes

of additional aortic cross-clamp time, and the risk of perioperative bleeding is considered minimal. After the Maze procedure, warfarin is routinely administered to all patients for 3 months. If sinus rhythm is constantly maintained, anticoagulation therapy is terminated in patients with mitral valve repair or biological valve implantation. Small dosages of aspirin are given if the contraction of the left atrium is absent or left atrial dimension is greater than 55 mm.

In conclusion, mitral valve repair concomitant with the Maze procedure may be valuable and rationalized in order to decrease the late complications associated with anticoagulation, and thus improve the quality of life of patients with EDS.

REFERENCES

1. Pepin M, Schwarze U, Superti-Furga A, Byers PH. Clinical and genetic features of Ehlers-Danlos syndrome type IV, the vascular type. N Engl J Med 2000;342:673–80.
2. Mattar SG, Kumar AG, Lumsden AB. Vascular complications in Ehlers-Danlos syndrome. Am Surg 1994;60:827–31.
3. Byers PH. Ehlers-Danlos syndrome: recent advances and current understanding of the clinical and genetic heterogeneity. J Invest Dermatol 1994;103:47S–52S.
4. Fuzellier JG, Chauvaud SM, Fornes P, Berrebi AJ, Lajos PS, Bruneval P, et al. Surgical management of mitral regurgitation associated with Marfan's syndrome. Ann Thorac Surg 1998;66:68–72.
5. Gillinov AM, Hulyalkar A, Cameron DE, Cho PW, Greene PS, Reitz BA, et al. Mitral valve operation in patients with the Marfan syndrome. J Thorac Cardiovasc Surg 1994;107:724–31.
6. Avlonitis VS, Large SR. Ehlers-Danlos syndrome: surgical management of mitral regurgitation and atrial fibrillation. J Heart Valve Dis 1999;8:463–5.
7. Kitagawa M, Nakagawa Y, Shibairi M, Yasuno K, Okimoto M, Masuda M, et al. Mitral valve replacement in a case of the Ehlers-Danlos syndrome. Nippon Kyobu Geka Gakkai Zasshi 1984;32:1073–7.
8. Nakajima H, Kobayashi J, Bando K, Niwaya K, Tagusari O, Sasako Y, et al. The effect of cryo-maze procedure on early and intermediate term outcome in mitral valve disease: case matched study. Circulation 2002;106:146–150.

ELSEVIER

European Journal of Cardio-thoracic Surgery 27 (2005) 1114

EUROPEAN JOURNAL OF
CARDIO-THORACIC
SURGERY

www.elsevier.com/locate/ejcts

Images in cardio-thoracic surgery

Aortic valve replacement concomitant with multiple extra-anatomical bypasses for a patient with aortic valve insufficiency having Takayasu's arteritis

Akinobu Itoh, Junjiro Kobayashi, Osamu Tagusari*, Soichiro Kitamura

Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishirodai, Sita, Osaka 565-8565, Japan

Received 14 December 2004; received in revised form 5 February 2005; accepted 8 February 2005; Available online 23 March 2005

Keywords: Takayasu's arteritis; Aortic valve insufficiency; Extra-anatomical bypass

A 58-year-old woman, who had suffered from Takayasu's arteritis, presented heart failure and abdominal angina due to severe aortic insufficiency, stenosis of the abdominal aorta and bilateral subclavian arteries. Simultaneous aortic valve replacement and multiple extra-anatomical bypasses led to an improvement in cardiac function and a relief of digestive symptom (Figs. 1 and 2).

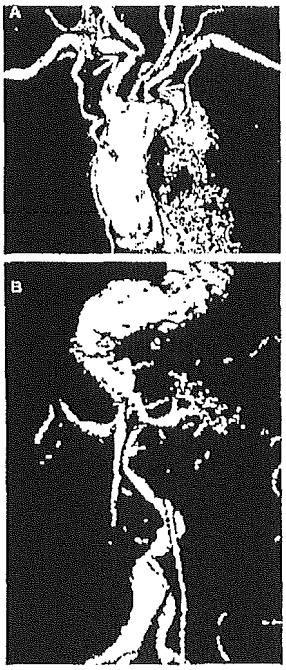

Fig. 1. Preoperative magnetic resonance angiographies showed severe stenosis of the bilateral subclavian arteries (A) (white arrows), and the abdominal aorta at the level of the superior mesenteric artery to the terminal aorta (B).

Fig. 2. A postoperative three-dimensional computed tomography scan at two months after operation demonstrated a 16-mm Dacron graft anastomosed to the ascending aorta and the right external iliac artery placed through the pre-peritoneal space, and 8-mm ringed Dacron grafts anastomosed to the 16-mm Dacron graft and the bilateral axillary arteries. Developed complex arterial connections among the branches of visceral arteries were described (white arrows).

* Corresponding author. Tel.: +81 6 6833 5012; fax: +81 6 6872 7486.
E-mail address: otagusar@hsp.ncvc.go.jp (O. Tagusari).

doi:10.1016/j.ejcts.2005.02.013

EDITORIAL

Does the internal thoracic artery graft have self-reparative ability?

Soichiro Kitamura, MD

See related article on page 1661.

Accumulating clinical[1-3] and basic[4,5] evidence with regard to the internal thoracic artery (ITA) as a viable graft has revealed that this arterial graft for coronary bypass surgery is not a simple conduit to transport blood to the myocardium. It has a character of the major collateral pathway[6] with active biologic potency, such as immunity from the atherosclerotic process, active dilatation and resultant arterial wall remodeling, excellent endothelial secretion of nitric oxide and other biologically active substances, active thinning (string phenomenon) with no-flow patency (nonworking collateral vessel), reestablishment of graft flow depending on the myocardial demand, and the phenomenon that we can call the "self-reparative ability," as published in this issue of the *Journal*.[7]

It has previously been demonstrated that the ITA graft can grow in longitudinal length and transverse diameter in response to somatic growth of children with coronary obstruction.[8] This is the most clear-cut evidence to show that the ITA graft is a viable structure. Moreover, the ITA graft caliber at the anastomotic junction can also grow in children.[9] Probably the same mechanism can work on the stenotic anastomotic sites in adults, with resultant late reduction in the grade of anastomotic stenosis located between the ITA graft and the recipient coronary artery, as shown in the article by Izumi and colleagues.[7] Within 14 days after a bypass operation, ITA flow can show a several-fold increase with a 1.5 times increase in diameter.[10] The ITA graft responds to an acute increase in flow by vasodilatation most importantly by release of nitric oxide, a potent vasodilator derived from the highly active endothelium of the ITA[11] induced by increased shear stress to the arterial wall. Shear stress–induced nitric oxide release occurs in a matter of several seconds through the calcium-dependent constitutive form of nitric oxide synthase activation.[12] The ITA graft can maintain the secretory ability of nitric oxide long after the bypass operation.[13,14] Nitric oxide is released bidirectionally by the endothelium.[15] Extraluminal nitric oxide acts on the underlying vascular smooth muscle regulating the vascular tone and inhibits neointimal proliferation. This action might be effective in making anastomotic stenoses less fibrotic. Intraluminal nitric oxide is released into the blood stream and can be demonstrated long after the bypass operation through activation of the ITA endothelium with acetylcholine.[13] Intraluminally released nitric oxide protects platelet aggregation and adhesion and might have a metabolic effect on the downstream vascular beds.[16] In this sense I think we can call ITA grafting autologous transplantation of the good-quality arterial endothelium into the coronary circulation that has impaired endothelial function with atherosclerosis.[13] Excellent nitric oxide production of the ITA endothelium will prevent further atherosclerotic process for both grafts and grafted coronary arteries, and as a matter of fact, atherosclerotic progression of the coronary artery distal to the ITA graft anastomosis is infrequent.[17] In addition, following revascularization with ITA grafts, coronary vasospastic response to ergonovine is significantly ameliorated or disappears at the segment distal to the ITA graft anastomosis. This phenomenon has been documented by angiography with pharmacologic intervention[18] and can be considered as a proof of the beneficial metabolic effect of the ITA graft, that is an antispastic effect of the ITA graft on vasospastic coronary arteries.

ITA grafts act differently from vein grafts on progression of grafted coronary artery stenosis proximal to the anastomosis. Angiographic progression of grafted coronary artery stenosis is 18% for ITA grafts versus 46% for vein grafts in one

From the National Cardiovascular Center, Osaka, Japan.

Received for publication Aug 16, 2005; accepted for publication Aug 22, 2005.

Address for reprints: Soichiro Kitamura, MD, National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan (E-mail: skitamur@hsp.ncvc.go.jp).

J Thorac Cardiovasc Surg 2005;130:1494-5

0022-5223/$30.00

doi:10.1016/j.jtcvs.2005.08.030

series,[3] and 26% versus 45%,[19] 12% versus 38%,[20] and 39% versus 67%[17] in other series. These differences are all statistically significant. Progression occurs less frequently in coronary arterial segments bypassed with ITA grafts than in those bypassed with vein grafts. This fact is believed to be attributed to characteristics of the viable ITA graft's function as a major collateral channel. On the basis of these facts, I believe that the ITA graft has a potential metabolic effect that protects the grafted coronary arteries from vasospastic responses and atherosclerotic progression, resulting in longer survival of the patients with more ITA grafts than those without ITA grafts.[21] This salutary metabolic effect of the ITA graft cannot be expected from coronary stents alone. In the present article by Izumi and colleagues,[7] the physiologic response and adaptability of the ITA graft is again demonstrated in terms of the self-reparative ability that can be expected only in a viable graft.

This article also gives rise to an important clinical issue, particularly in the era of off-pump coronary artery bypass, during which anastomotic complications possibly increase. The issue is whether early postoperative angiographic confirmation is needed more than before in the off-pump coronary artery bypass era. Early postoperative angiographic assessment is rather common in Japan but not so in Western counterparts, mainly because of the difference in social insurance coverage. According to the present report, early postoperative angiography is not necessary for the purpose of evaluating ITA graft anastomosis unless the patient shows some types of myocardial ischemia. In addition, intraoperative measurements and evaluation of graft flow with its pattern analysis can provide relatively accurate clues to detect anastomotic failure during an operation. With this technology, surgeons can handle it inside the operating room. In other words, as long as the ITA is adequately handled and anastomosed in the operating room, there is not much to worry about with regard to ITA graft status thereafter. This is certainly good information for surgeons. Also, cardiologists who perform early angiography for the purpose of their own confirmation and sometimes evaluation of surgeons should also realize this fact. However, when a tight (>80%-90%) anastomotic stenosis is found at angiography performed for any reason, I believe that balloon dilatation should be applied because this procedure is safe and long lasting[22] and might prevent the ITA graft occlusion (thrombosis) that occurs at the rate of a few percent, usually as a result of some technical mishap. Simple balloon dilatation is quite satisfactory, with no need for stenting.

References

1. Cosgrove DM, Loop FD, Saunders CL, Lytle BW, Kramer JR. Should coronary arteries with less than fifty percent stenosis be bypassed? *J Thorac Cardiovasc Surg.* 1981;82:520-30.
2. Barner HB. Remodeling of arterial conduits in coronary grafting. *Ann Thorac Surg.* 2002;73:1341-5.
3. Kitamura S, Kawachi K, Morita R, Kobayashi H, Nishii T, Taniguchi S, et al. Results of internal mammary artery-coronary artery bypass surgery and the characteristics of internal mammary artery grafts. *Jpn Circ J.* 1987;51:1052-60.
4. Ignarro LJ, Buga GM, Wood KS, Byrns RE, Chaudhuri G. Endothelium-derived relaxing factor produced and released from artery and vein is nitric oxide. *Proc Natl Acad Sci U S A.* 1987;84:9265-9.
5. Lüscher TF, Diederich D, Siebenmann R, Lehmann K, Stulz P, von Segesser L, et al. Difference between endothelium-dependent relaxation in arterial and venous coronary grafts. *N Engl J Med.* 1988;319:462-7.
6. Kitamura S, Kawachi K, Seki T, Sawabata N, Morita R, Kawata T. Angiographic demonstration of no-flow anatomical patency of internal thoracic-coronary artery bypass grafts. *Ann Thorac Surg.* 1992;53:156-9.
7. Izumi C, Hayashi H, Ueda Y, Matsumoto M, Himura Y, Gen H, et al. Late regression of left internal mammary artery graft stenosis at the anastomotic site without intervention therapy. *J Thorac Cardiovasc Surg.* 2005;130:1661-7.
8. Kitamura S, Seki T, Kawachi K, Morita R, Kawata T, Mizuguchi T, et al. Excellent patency and growth potential of internal mammary artery grafts in pediatric coronary artery bypass surgery. New evidence for "live" conduit. *Circulation.* 1988;78(suppl I):I129-39.
9. Kitamura S, Kawachi K, Seki T, Morita R, Nishii T, Mizuguchi K, et al. Bilateral internal mammary artery grafts for coronary artery bypass operation in children. *J Thorac Cardiovasc Surg.* 1990;99:708-15.
10. Tagusari O, Kobayashi J, Bando K, Niwaya K, Nakajima H, Ishida M, et al. Early adaptation of the left internal thoracic artery as a blood source of Y-composite radial artery grafts in off-pump coronary artery bypass grafting. *Heart Surg Forum.* 2003;6:522-7.
11. He GW, Liu ZG. Comparison of nitric oxide release and endothelium-derived hyperpolarizing factor-mediated hyperpolarization between human radial and internal mammary arteries. *Circulation.* 2001;104:1344-9.
12. Kanai AJ, Strauss HC, Truskey GA, Crews AL, Grunfeld S, Malinski T. Shear stress induces ATP-independent transient nitric oxide release from vascular endothelial cells, measured directly with a porphyrinic microsensor. *Circ Res.* 1995;77:284-93.
13. Nishioka H, Kitamura S, Kameda Y, Taniguchi S, Kawata T, Mizuguchi K. Difference in acetylcholine-induced nitric oxide release of arterial and venous grafts in patients after coronary bypass operations. *J Thorac Cardiovasc Surg.* 1998;116:454-9.
14. Kushwaha SS, Bastami M, Tadjkarimi S, Ilsley CDJ, Mitchell AG, Yacoub MH. Late endothelial function of free and pedicled internal mammary artery grafts. *J Thorac Cardiovasc Surg.* 1995;110:453-62.
15. Moncada S, Palmer RMJ, Higgs EA. Nitric oxide: physiology, pathophysiology and pharmacology. *Pharmacol Rev.* 1991;43:109-42.
16. Kalm M, Schrader J. Control of coronary vascular tone by nitric oxide. *Circ Res.* 1990;66:1561-75.
17. Loop FD. Internal-thoracic-artery grafts. Biologically better coronary arteries. *N Engl J Med.* 1996;334:263-5.
18. Kitamura S, Morita R, Kawachi K, Iioka S, Saki T, Inoue K, et al. Different responses of coronary artery and internal mammary artery bypass grafts to ergonovine and nitroglycerin in variant angina. *Ann Thorac Surg.* 1989;47:756-60.
19. Manninen H, Jaakkola P, Suhonen M, Rehnberg S, Vuorenniemi R, Matsi PJ. Angiographic predictors of graft patency and disease progression after coronary artery bypass grafting with arterial and venous grafts. *Ann Thorac Surg.* 1998;66:1289-94.
20. Hamada Y, Kawachi K, Yamamoto T, Nakata T, Kashu Y, Watanabe Y, et al. Effects of coronary artery bypass grafting on native coronary artery stenosis. *J Cardiovasc Surg.* 2001;42:159-64.
21. Lytle BW, Blackstone EH, Sabik JF, Houghtaling P, Loop FD, Cosgrove DM. The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. *Ann Thorac Surg.* 2004;78:2005-14.
22. Najm HK, Leddy D, Hendry PJ, Marquis JF, Richardson D, Keon WJ. Postoperative symptomatic thoracic artery stenosis and successful treatment with PTCA. *Ann Thorac Surg.* 1995;59:323-7.

ELSEVIER

European Journal of Cardio-thoracic Surgery 27 (2005) 807-814

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Long-term outcome of right ventricular outflow tract reconstruction using a handmade tri-leaflet conduit☆

Masahiro Koh, Toshikatsu Yagihara*, Hideki Uemura, Koji Kagisaki, Ikuo Hagino, Toru Ishizaka, Soichiro Kitamura

Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishiro-dai, Suita, Osaka 565-8565, Japan

Received 5 October 2004; received in revised form 17 January 2005; accepted 25 January 2005; Available online 11 March 2005

Abstract

Objective: Since 1985, we have implanted handmade tri-leaflet conduits made of heterologous pericardium or expanded polytetrafluoroethylene (ePTFE), as an alternative to homograft for right ventricular outflow tract reconstruction. This report assesses the long-term outcome of these prostheses. **Methods:** From 1985 to 2003, 216 handmade tri-leaflet conduits were implanted in 191 patients. Forty-two patients had previous conduit repairs. The mean age at operation was 8.1±7.7 years (range: 15 days-44 years). The underlying diagnoses were pulmonary atresia with ventricular septal defect in 83 patients, atrioventricular discordance in 36, transposition of the great arteries in 26, double outlet right ventricle in 14, and truncus arteriosus in 17. Whole heterologous pericardial tri-leaflet conduits were implanted in 169 patients, in the early series (porcine: 85; equine: 58; bovine: 26); bovine pericardial conduits containing ePTFE leaflets were implanted in 26 patients since 1996; whole ePTFE tri-leaflet rolls were employed in the most recent 21 patients. The conduit size was 21.1±3.1 mm (range: 12-27 mm), 147.4±21.4% (range: 82.6-202.6%) of the anticipated diameter of the pulmonary valve. Follow-up was complete. **Results:** There were 28 early deaths and 24 late deaths. The indication for conduit replacement was a peak instantaneous pressure gradient of greater than 50 mmHg. Sixty-five conduits required reoperation for conduit obstruction at 8.6±3.3 years after implantation. The freedom from reoperation at 5, 10, and 15 years was 93.9±1.9, 61.4±4.5, and 35.5±5.6%, respectively. Patients with smaller conduit size and young age at operation were predisposed to reoperation. None of the 47 ePTFE tri-leaflet conduits developed significant obstruction. The freedom from important pulmonary valve regurgitation (PR) as assessed by echocardiography was 68.3±3.7% at 5 years, 33.0±4.5% at 10 years, and 21.6±4.9% at 15 years. No patient required reoperation due to PR or right ventricular dysfunction. **Conclusions:** Handmade tri-leaflet conduits provide a reliable alternative for RVOT reconstruction in children, yielding as good a long-term outcome as do homografts. Longer follow-up is needed to determine how well ePTFE leaflets will fare.

Keywords: Right ventricular outflow tract reconstruction; Homograft; Pulmonary valved conduit; Polytetrafluoroethylene

1. Introduction

Valved conduits are frequently used for right ventricular outflow tract reconstruction (RVOTR) for a wide range of congenital heart diseases. The ideal choice for a valved conduit, however, has yet to be found. Desired characteristics include availability, ease of implantation, and longevity. From the early 1970s, commercially available porcine-valved Dacron conduits had been used in many institutes, including our own [1,2]. However, the results were disappointing, characterized by poor handling, excessive intimal fibrocalcific peel formation, and degeneration of the porcine valve—particularly when implanted in children [3,4]. Eventually, the porcine-valved Dacron conduit gave way to the cryopreserved homograft conduit [5]. Although homograft conduits remain the popular choice, certain disadvantages—such as lack of sufficient availability, the requirement of sterilization and preservation, and late complications due to degenerative processes and calcifications—have led us to search for other alternatives. Commencing in 1985 we developed a hand-made tri-leaflet conduit made of glutaraldehyde-fixed heterologous pericardium, which we call the "valved pericardial roll (VPR)", as a potential alternative to homograft conduits [6-8]. Then, in 1996, we introduced expanded polytetrafluoroethylene (ePTFE) leaflets in order to avoid the degenerative characteristics of heterologous pericardium. In this study we reviewed the long-term outcome of 216 handmade tri-leaflet conduits. We assessed the long-term durability, valve function, and risks of reoperation, in order to clarify the optimal surgical strategy for better outcome. In addition, the intermediate characteristics of the ePTFE leaflets were reviewed.

☆Presented at the joint 18th Annual Meeting of the European Association for Cardio-thoracic Surgery and the 12th Annual Meeting of the European Society of Thoracic Surgeons, Leipzig, Germany, September 12-15, 2004.

* Corresponding author. Tel.: +81 6 6833 5012; fax: +81 6 6872 7486.
E-mail address: yagihara@hsp.ncvc.go.jp (T. Yagihara).

1010-7940/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejcts.2005.01.060

Table 1
Primary diagnosis

Diagnosis	Number of implanted handmade conduits	Number of patients	Initial conduit implantation	Having previous porcine valved conduit implantation	Having previous handmade conduit implantation
PA and VSD with MAPCAs	61	50	49	1	11
PA and VSD without MAPCAs	38	33	29	4	5
AVD (anatomical repair)	31	27	27	0	4
AVD (functional repair)	10	9	7	2	1
TGA	27	26	23	3	1
DORV	17	16	11	5	1
Truncus arteriosus	14	12	11	1	2
TF with absent pulmonary valve	6	6	6	0	0
Univentricular heart (ventricular septation)	5	5	5	0	0
Aortic valve pathology (Ross procedure)	3	3	3	0	0
Others	4	4	3	1	0
Total	216	191	174	17	25

PA, pulmonary atresia; VSD, ventricular septal defect; MAPCA, major aortopulmonary collateral arteries; TGA, transposition of the great arteries; DORV, double outlet right ventricle; TF, tetralogy of Fallot.

2. Materials and methods

Between October 1985 and June 2004, 216 handmade tri-leaflet conduits were implanted in 191 patients in order to re-establish continuity between the pulmonary ventricle and the pulmonary arteries, at National Cardiovascular Center in Osaka, Japan. One hundred and seventy-four were primary conduit repairs; 42 had had previous conduit implantation: porcine-valved Dacron conduit in 17, and handmade tri-leaflet conduit in 25 (Table 1).

2.1. Patient characteristics

The mean age at operation was 8.1±7.7 years old (range: 15 days-44 years); 7.2±7.6 years old for initial implantation, and 14.3±5.0 years old for reoperation. There were 18 infants including one neonate. The diagnostic categories are summarized in Table 1. There was pulmonary atresia and ventricular septal defect with major aortopulmonary collateral arteries (PA-VSD with MAPCAs) in 50 patients, PA-VSD without MAPCAs in 33, atrioventricular discordance (AVD) in 36, transposition of the great arteries in 26, double outlet right ventricle in 16,and truncus arteriosus in 12. In nine of the 36 patients with AVD, functional biventricular repair using a left ventricle–pulmonary artery conduit was performed [9]; the other 27 patients underwent anatomical biventricular repair, double switch operation, in which a conduit was inserted between the anatomical right ventricle and the pulmonary artery [10]. As preparative procedures, 41 patients with aplasia or hypoplasia of intrapericardial pulmonary arteries required intrapulmonary pulmonary artery reconstruction with heterologous pericardial roll, prior to definitive conduit repair [11-13].

2.2. Handmade tri-leaflet conduits

Prior to the operation, a tri-leaflet conduit was manufactured on the operating table. Conduit size was determined to be almost always larger than the anticipated pulmonary valve diameter, if the sternum allowed. Mean conduit size was 21.1±3.1 mm (range: 12-27 mm), 147.4±21.4% (range: 82.6-202.6%) of the anticipated diameter of the pulmonary valve (Fig. 1).

2.2.1. Original style: "Whole heterologous pericardium" (1985-1996)

A piece of heterologous pericardial rectangular patch, with a width of approximately three times the conduit diameter, was prepared (Fig. 2). The base of the rectangle was turned up and each trichotomy line was sutured with 5-0 or 6-0 polypropylene sutures so as to create three leaflets. In general, the height and the width of the leaflets were the same as the conduit diameter, as determined by our laboratory studies [8]. Then, the rectangle with the tri-leaflet was wrapped around the corresponding Hagar's dilator and the conduit was closed with 5-0 polypropylene continuous sutures—so as to create a pericardial roll containing a valve structure. An additional conduit of the same size was constructed which was to be inserted between the ventriculotomy and the valved pericardial roll. The upper and lower ends of the conduit were left open, to allow the surgeon to tailor these to each patent's needs. Originally, we used glutaraldehyde-fixed porcine pericardium (Rygg; Polystan AS, Copenhagen, Denmark) as the material in 82 consecutive conduits. In the pursuit of optimal valve function, we changed the material of the tri-leaflet

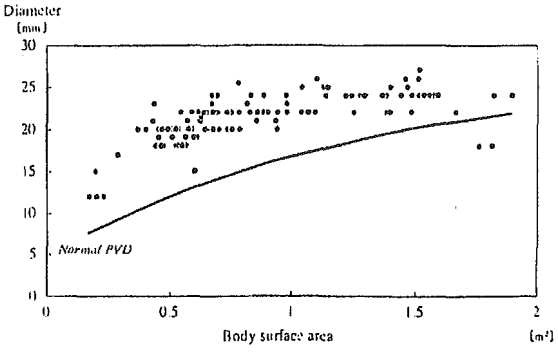

Fig. 1. Correlation between conduit size and body surface area.

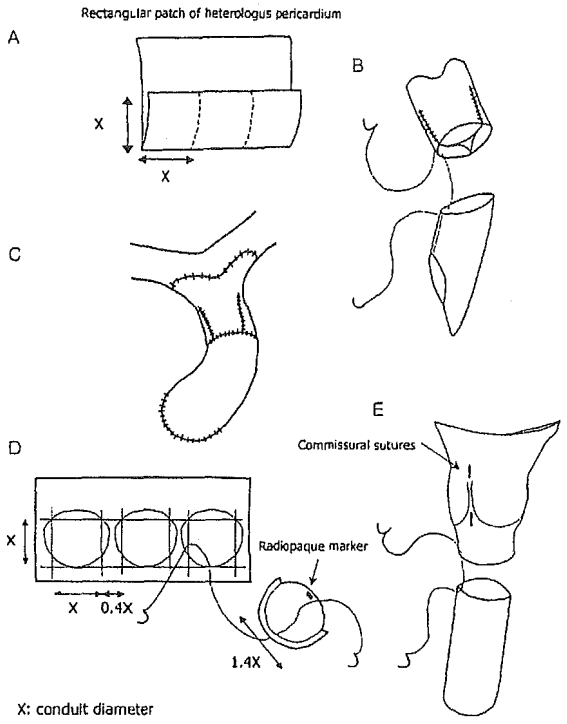

Fig. 2. Construction of handmade tri-leaflet conduit (A-C: original style, D-E: modified style). (A) A rectangular patch of heterologous pericardium with a width of three times the conduit diameter is prepared. Its base is turned up and divided into three parts. Each trichotomy line is sutured to the confronting patch to create the leaflet. As a rule, the height of the leaflet is equal to the conduit diameter. (B) The rectangular patch containing the tri-leaflet assembly is rolled up and closed. (C) An additional conduit is inserted between the valved conduit and the ventriculotomy. (D) A 0.1-mm thick ePTFE sheet is trimmed to become a semi-oval shaped leaflet. The height is equal to the conduit diameter and the width is 140% of the conduit diameter. A small piece of radiopaque marker is attached to the center of the edge of each leaflet. (E) Each commissure is plicated with pairs of horizontal mattress stitches. This ploy produces the mildly bulging profile of the sinus.

conduit, sequentially (Table 2). Equine pericardium (Xenomedica; Baxter, Chicago, IL) was employed in 58 conduits, from 1990 to 1993, followed by bovine pericardium (No React; Shelhigh, Millburn, NJ, or PeriGuard; Bio-Vascular, Inc., St Paul, MN) in 26, from 1993 to 1996.

2.2.2. *Modified style "ePTFE leaflets" (1996~)*

In November 1996 we abandoned glutaraldehyde-treated heterologous pericardial leaflets and employed ePTFE leaflets. A 0.1 mm-ePTFE sheet (Gore-Tex Pericardial Membrane; W.L. Gore and Assoc., Newark, DE) to be used for the leaflets was cut in a nearly semi-oval shape with the base measuring approximately 140% of the conduit diameter, and the height equal to the conduit diameter. In practice, we cut the leaflets to be more generous than the actual measurement—with a seam allowance of 3 mm. Then, the edge of each ePTFE leaflet was secured to a rectangular piece cut from bovine pericardium, or, from 2000 to present, a piece cut from ePTFE prosthetic vascular graft (Gore-Tex stretch vascular graft) using 5-0 polypropylene continuous sutures. Care was taken not to make undesirable folds in the leaflet patch. Then, a small piece of radiopaque marker (A/C Locator graft marker; Scanlan International, St Paul, MN) was attached, using 6-0 polypropylene sutures at the center of the free edge of each ePTFE leaflet, to imitate the natural thickening of the edge of the normal human semi-lunar valve imitating the nodule of Arantius. We expect this ploy to assist natural motion of the leaflet. In addition, this marker allows postoperative radiological assessment of leaflet function. Pairs of horizontal mattress sutures were placed at each commissural portion, producing a mildly bulging profile similar to the sinus of Valsalva, to encourage natural blood-flow patterns and leaflet motion.

Table 2
Changes of material

Original style "Whole heterologous pericardium"		
10/1985-	Porcine valved pericardial roll	85
6/1990-	Equine valved pericardial roll	58
5/1993-	Bovine valved pericardial roll	26
Modified style "ePTFE leaflets"		
11/1996-	ePTFE leaflets+Bovine pericardial conduit	26
10/2000-	ePTFE leaflets+ePTFE conduit	21

2.3. *Operative techniques*

All patients were approached by median sternotomy. Hypothermic extracorporeal circulation with cold antegrade crystalloid cardioplegia was used. If the operation was confined to the right side of the heart, the aorta was not cross-cramped. In 37 patients with non-confluent central pulmonary artery, reconstruction of the central pulmonary artery with heterologous pericardial roll was carried out concomitantly [13]. Surgical correction of the pulmonary artery branches was necessary in 18 patients. The stenotic area was enlarged mostly with a piece of autologous or heterologous pericardial patch, followed by distal anastomosis of the conduit. The distal end of the conduit was trimmed and beveled, and an end-to-end anastomosis between the distal conduit and the proximal pulmonary bifurcation was performed using continuous 6-0 polypropylene sutures. Care was taken to tilt the conduit plane to the pulmonary artery and to create a large anastomosis. We expect this maneuver to not only prevent compression of the valve between the heart and the sternum but to minimize turbulent blood flow. An additional conduit was inserted between the tri-leaflet conduit and the ventriculotomy, tailoring its proximal end in an S-shaped manner so as to avoid a gradient at the transition of the ventriculotomy.

2.4. *Patient follow-up*

There were 28 early deaths; AVD in 7, VSD and PA with MAPCAs in 6, TGA in 5, DORV in 4, and others in 6. All surviving patients had periodic follow-up at our institution. Follow-up was 100% complete and ranged from 1 month to 18 years, with a mean of 8.5 ± 5.9 years. All were given warfarin sodium and low-dose antiplatelet drugs for at least 1 year after conduit implantation.

Recently, routine postoperative catheterization was carried out in most cases at approximately 1 year after the operation. During catheterization, the radiopaque markers attached to the ePTFE leaflets could be easily visualized, allowing convenient assessment of leaflet motion. We assessed the motion of the ePTFE leaflets in 25 conduits.

The indication for reoperation was persistent pressure gradient across the conduit of greater than 50 mmHg.

2.5. Echo examinations

All patients were examined in the immediate postoperative period and reexamined serially with transthoracic echocardiograms every 6-12 months. Pulmonary valve regurgitation (PR) was assessed by looking at the regurgitant jet with pulsed color-flow Doppler; of particular interest was the width of the jet at its source and its penetration depth into the ventricle. PR was graded subjectively as follows: none, slight, mild, moderate, or severe. If PR was equal to or greater than moderate, it was considered to be important. For seven patients the echocardiographic windows were inadequate to allow comment on valve function, and for another three patients serial analysis was unavailable: the echocardiographic follow-up was therefore complete in 206 conduits (95.4%).

2.6. Data analysis

Data are presented as the mean ± the standard deviation. All statistical tests were conducted with JMP 5.1.1 software (SAS Institute, Inc., Cary, NC). The cumulative survival estimates were made by the Kaplan-Meier method. The log-rank test was applied for comparison between time-related variables. Values of $p<0.05$ were considered significant.

3. Results

3.1. Mortality and morbidity

Four patients developed postoperative mediastinitis, probably due to prolonged sternal splintage in three and unexpected esophageal rupture in one. Three died and one was successfully treated by conduit renewal with omental flap closure. Four patients developed late conduit infection; antibiotic therapy was effective in 3. One patient who developed fulminating fungal infection 10 months after implantation required urgent conduit replacement. Eventually, he died of refractory fungal infection. One patient died from thrombus formation in the conduit. Twenty-four patients died late. There were 14 sudden deaths or arrhythmia-related deaths. Three patients died at reoperation. Overall survival after initial conduit implantation was 79.2±3.0% at 5 years, 74.0±3.3% at 10 years, and 70.4±3.8% at 15 years.

3.2. Reinterventions

Of the 193 survivors, 24 (12.4%) underwent balloon dilatation and 68 (34.2%) required reoperations. Two patients required replacement of an infected conduit. One patient with PA-VSD with MAPCAs, who had an ePTFE tri-leaflet conduit, developed severe aortic valve regurgitation 2 years after the operation. She underwent aortic valve replacement concomitant with conduit replacement using a porcine stentless valve. Although the ePTFE leaflets were pliable and utterly unobstructive in this particular patient, we exchanged the conduit because a more competent valve would be advantageous in the presence of elevated

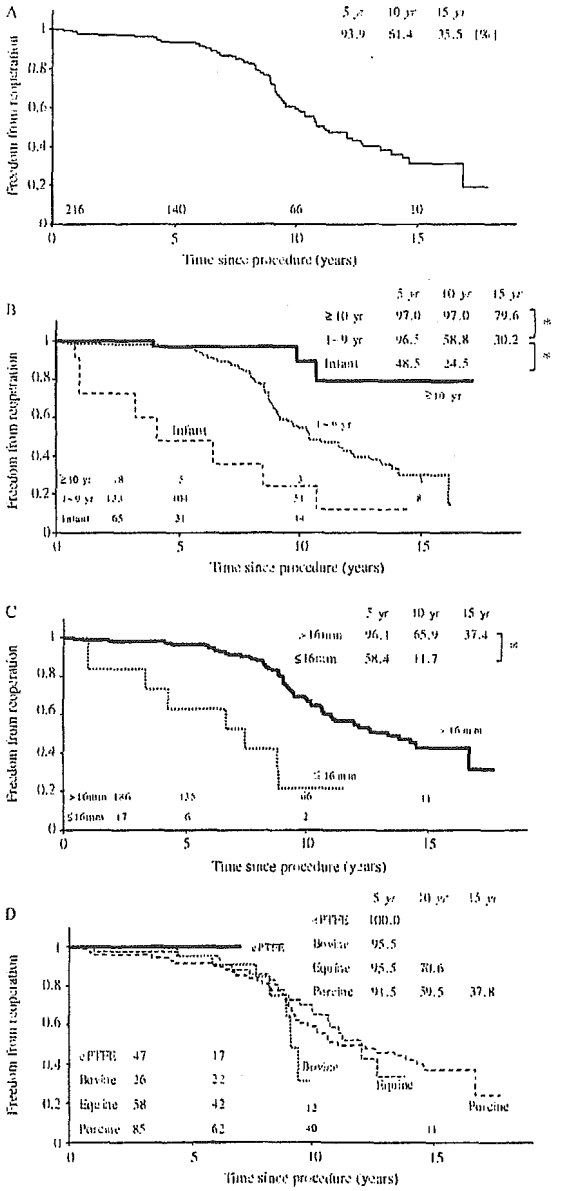

Fig. 3. Freedom from reoperation (Kaplan-Meier curve). An asterisk indicates statistical significance ($p<0.001$). (A) Overall freedom from reoperation. (B) Freedom stratified according to age. (C) Freedom stratified according to conduit size. (D) Freedom stratified according to the leaflet material.

pulmonary vascular resistance and deteriorated ventricular function. Eventually, 65 conduits were replaced due to obstructive disease within 5 months-17 years after the primary operation (mean: 8.6±3.3 years). All of these were original valved pericardial rolls (porcine: 37; equine: 21; bovine: 7). The most stenotic portion was associated with calcified pericardial leaflets in 55 conduits and excessive peel formation in 10. Virtually all 47 ePTFE tri-leaflet conduits have been free from calcification or important obstruction over a follow-up period that ranged from 1 month-7 years (mean: 3.1±0.3 years).

Regarding the techniques of reoperation, the anterior patching method using autologous tissue, as described by Danielson et al. [4,14], was carried out in 38 cases. A second handmade tri-leaflet conduit was inserted in 25 cases, a non-valved tube in 4, and a stentless porcine valve in 1. There were three mortalities associated with reoperation (4.4%). Two patients died from severe neurological complications. One patient died from massive postoperative bleeding due to detachment of the distal anastomosis.

Fig. 3 plots the estimates of freedom from reoperation. At 5, 10, and 15 years this was 93.9±1.9, 61.4±4.5, and 35.5±5.6%, respectively. The freedom from reintervention, including balloon dilatation or reoperation for conduit obstruction, was 92.6±2.1, 52.6±4.6, and 23.3±4.8% at the respective time points.

Cases with smaller conduit size and young age at operation were predisposed to reoperation. With regard to the leaflet material, no detectable difference was observed between the three kinds of heterologous pericardial leaflets.

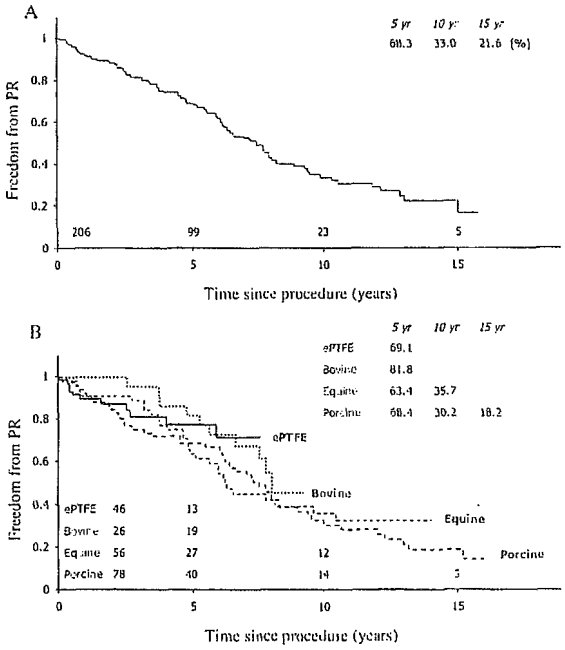

Fig. 4. Freedom from PR. (A) Overall freedom from PR. (B) Freedom from PR stratified to the leaflet material.

3.3. Pulmonary valve regurgitation

The echocardiographic analysis showed that freedom from important PR was 68.3±3.7% at 5 years, 33.0±4.5% at 10 years, and 21.6±4.9% at 15 years. No significant difference was detected between the leaflet materials (Fig. 4).

3.4. Motion of ePTFE leaflets

Of the 75 ePTFE leaflets comprising 25 conduits, 69 (92%) were functioning well 1 year after the operation (Fig. 5). Four leaflets were completely fixed in the open position and two leaflets had restrictive motion. No ePTFE leaflet had detectable calcification.

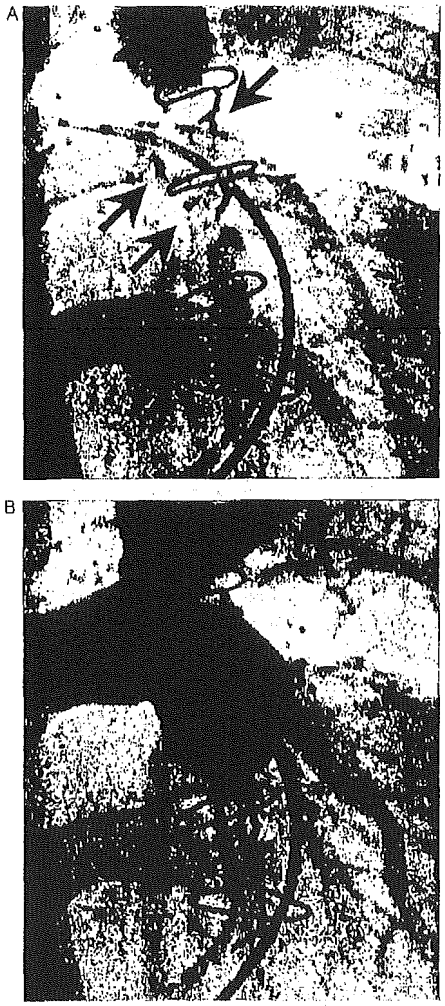

Fig. 5. Postoperative angiography of ePTFE tri-leaflet conduit (18-year-old male, PA-VSD, 1 year after implantation). (A) Radiopaque markers can be identified (arrows). (B) EPTFE leaflets are functioning satisfactorily.

4. Discussion

Homograft conduits have become the most widely used conduit type in RVOTR. However, the short supply of homografts is a considerable problem. Particularly in Japan, there have been difficulties in popularizing of allotransplantation because of cultural background. Although we have our own tissue bank, the availability of homografts remains limited. Porcine-valved Dacron conduits have been another common option. However, although they are convenient to use and easily available, their handling is problematic and they are vulnerable to secondary obstruction [2-4].

The difficulty of utilizing homografts and the unsatisfactory results of previous porcine-valved Dacron conduits led us to produce handmade tri-leaflet conduits made of heterologous pericardium. Pericardial conduits have clear advantages in comparison with porcine-valved Dacron conduits. The biological characteristics of the pericardial tissue match quite well with the pulmonary arteries, allowing easier handling and excellent hemostasis at the suture lines. The pericardial conduits are less bulky in the children's chest than are prosthetic valved conduits. Handmade tri-leaflet conduits are, obviously, available in any sizes. The quality of the handmade tri-leaflet conduit was investigated in our earlier series, demonstrating favorable valve function and potential longevity, and we have adopted handmade tri-leaflet conduits as our standard technique for RVOTR, since 1985 [6-8]. Our present study reveals that long-term durability of our handmade tri-leaflet conduit is comparable to that of the pulmonary homograft conduit; 84-94% at 5 years, 80% at 8 years, and 58% at 10 years according to recent literatures. [15-17].

With regard to the leaflet material, we initially used porcine pericardium. To obtain better valve function and longer conduit life, we have varied the leaflet material with time. Equine pericardium was employed for the second generation, from 1990, and bovine pericardium for the third generation, from 1993. However, it appeared that no significant improvement was obtained. In general, glutaraldehyde-fixed heterologous pericardium was revealed to have a prominent inflammatory reaction, with calcification and shrinkage. Consequently, in 1996, we quit using heterologous pericardium as the leaflet material and employed ePTFE instead. This material has been used in the form of vascular conduits or to fill defects in many parts of the human body. Experimental and clinical experience indicates that ePTFE causes less calcification, thrombus formation, or intimal hyperplasia than does glutaraldehyde-fixed pericardium [18,19]. These advantages led some groups to employ an ePTFE monocusp in RVOTR [20,21]. Our experience indicates that an ePTFE tri-leaflet conduit can be expected to possess flexible valve behavior along with favorable durability. In early results, the ePTFE leaflets were moving freely and were well tolerated hemodynamically. Conversely, we found that the glutaraldehyde-fixed heterologous pericardial leaflets generally became fixed in the semi-closed or closed position, because of degeneration and calcification, eventually causing significant conduit obstruction. By contrast, when ePTFE leaflets became non-functional, they adhered to the conduit wall and became fixed in the open position without causing significant obstructive deterioration. We believe that ePTFE tri-leaflet conduits may be able to avoid leaflet-related stenotic complication for a lengthy period, if not definitely.

PR has been another concern with the valved conduit [22]. In our study, although the tri-leaflet conduits obviously functioned satisfactorily in the early postoperative phase, PR is ultimately inevitable. The incidence of PR was unrelated to the leaflet material. Certainly PR is malevolent, but it appears that PR was hemodynamically less significant in our study. There was no case that necessitated reoperation due to progressive PR or right ventricular dysfunction. In all cases in need of conduit replacement, conduit obstruction was the dominant lesion and PR was well tolerated. We believe that, although they may be imperfect in the long run, the use of a tri-leaflet conduit is beneficial—particularly for patients with elevated pulmonary vascular resistance or ventricular dysfunction, for whom competent valve function is helpful in the early postoperative period.

Our results show that younger age and smaller conduit size are risk factors for reoperation, as for pulmonary homograft conduits [15-17]. In infants or young children, valved conduits inevitably deteriorate and obstruct within the intermediate term. Accordingly, non-conduit repair using autologous tissue has become popular particularly in Japan. This technique may reduce the requirement for reoperation, although right ventricular dysfunction owing to PR might adversely influence the outcome [23-25]. Since 1992, our primary techniques of RVOTR for infants and young children have involved autologous tissue reconstruction, such as direct anastomosis between the pulmonary ventricle and the pulmonary artery. We reserve the use of hand-made tri-leaflet conduits for older children and adults.

Our anticoagulant regimen for handmade tri-leaflet conduit, warfarin sodium and low-dose antiplatelet drugs for at least 1 year, is experimental. We sometimes found small old clots inside the fixed leaflets of extirpated conduits. However, we have no case that developed clinically significant pulmonary embolism.

We are still seeking the optimal leaflet material as well as the optimal design, in order to obtain better valve function and longer conduit life. We have made some modifications in the design of the ePTFE tri-leaflet conduit, such as imitation of the natural bulges of the sinuses of Valsalva and the natural thickening of the nodules of Arantius. Although the efficacy of these modifications is not yet determined, we optimistically believe such modifications could make the handmade tri-leaflet conduit even more favorable.

In conclusion, our results show that RVOTR using a handmade tri-leaflet conduit is an acceptable alternative when homograft conduits are not always available. Although questions about long-term durability of the ePTFE leaflets remain unanswered, the intermediate outcomes are encouraging.

References

[1] Bowman Jr FO, Hancock WD, Malm JR. A valve-containing dacron prosthesis. Its use in restoring pulmonary artery-right ventricular continuity. Arch Surg 1973;107:724-8.

[2] Sano S, Kari TR, Mee RB. Extracardiac valved conduits in the pulmonary circuit. Ann Thorac Surg 1991;52:285-90.

[3] Jonas RA, Freed MD, Mayer Jr JE, Castaneda AR. Long-term follow-up of patients with synthetic right heart conduits. Circulation 1985;72: II77-II83.

[4] Dearani JA, Danielson GK, Puga FJ, Schaff HV, Warnes CW, Driscoll DJ, Schleck CD, Ilstrup DM. Late follow-up of 1095 patients undergoing operation for complex congenital heart disease utilizing pulmonary ventricle to pulmonary artery conduits. Ann Thorac Surg 2003;75: 399-410.

[5] Ross DN. Evolution of the homograft valve. Ann Thorac Surg 1995;59: 565-7.

[6] Kishimoto H, Yagihara T, Isobe F, Yamamoto F, Nishigaki K, Fujita T, Sato I, Arakaki Y, Takahashi O, Kamiya T. External conduit repair with 'valved pericardial roll'. Jpn J Thorac Cardiovasc Surg 1989;37: 658-63.

[7] Yagihara T, Kishimoto H, Yamamoto F, Nishigaki K, Matsuki O, Uemura H, Takahashi O, Kamiya T, Kawashima Y. One-stage repair in early infancy of tetralogy of Fallot with 'absent pulmonary valve' syndrome. Cardiol Young 1994;4:103-9.

[8] Fukaya Y, Yagihara T. Experimental study on the hydrodynamic performance of 'valved pericardial roll'. Jpn J Thorac Cardiovasc Surg 1993;41:1363-7.

[9] Koh M, Yagihara T, Uemura H, Kagisaki K, Kitamura S. Functional biventricular repair using left ventricle-pulmonary artery conduit in patients with discordant atrioventricular connections and pulmonary outflow tract obstruction—Does conduit obstruction maintain tricuspid valve function? Eur J Cardiothorac Surg 2004;26: 767-72.

[10] Yagihara T, Kishimoto H, Isobe F, Yamamoto F, Nishigaki K, Matsuki O, Uemura H, Kamiya T, Kawashima Y. Double switch operation in cardiac anomalies with atrioventricular and ventriculoarterial discordance. J Thorac Cardiovasc Surg 1994;107:351-8.

[11] Yagihara T, Yamamoto F, Nishigaki K, Matsuki O, Uemura H, Isizaka T, Takahashi O, Kamiya T, Kawashima Y. Unifocalization for pulmonary atresia with ventricular septal defect and major aortopulmonary collateral arteries. J Thorac Cardiovasc Surg 1996; 112:392-402.

[12] Ishizaka T, Yagihara T, Yamamoto F, Nishigaki K, Matsuki O, Uemura H, Yamashita K, Kamiya T, Kawashima Y. Results of unifocalization for pulmonary atresia, ventricular septal defect and major aortopulmonary collateral arteries: patency of pulmonary vascular segments. Eur J Cardiothorac Surg 1996;10:331-7.

[13] Uemura H, Yagihara T, Kawashima Y, Yamashita K, Kamiya T. Intra-pulmonary reconstruction of pulmonary arteries using a heterologous pericardial roll. Ann Thorac Surg 1995;59:1464-9.

[14] Danielson GK, Downing TP, Schaff HV, Puga FJ, DiDonato RM, Ritter DG. Replacement of obstructed extracardiac conduits with autogenous tissue reconstructions. J Thorac Cardiovasc Surg 1987;93:555-9.

[15] Bando K, Danielson GK, Schaff HV, Mair DD, Julsrud PR, Puga FJ. Outcome of pulmonary and aortic homografts for right ventricular outflow tract reconstruction. J Thorac Cardiovasc Surg 1995;109: 509-17.

[16] Stark J, Bull C, Stajevic M, Jothi M, Elliott M, de Leval M. Fate of subpulmonary homograft conduits: determinants of late homograft failure. J Thorac Cardiovasc Surg 1998;115:506-14.

[17] Niwaya K, Knott-Craig CJ, Lane MM, Chandrasekaren K, Overholt ED, Elkins RC. Cryopreserved homograft valves in the pulmonary position: risk analysis for intermediate-term failure. J Thorac Cardiovasc Surg 1999;117(1):141-6.

[18] Scavo Jr VA, Turrentine MW, Aufiero TX, Sun K, Binford R, Carlos G, Brown JW. Monocusp valve and transannular patch reconstruction of the right ventricular outflow tract: an experimental study. ASAIO J. 1998;44: 480-5.

[19] Izutani H, Gundry SR, Vricella LA, Xu H, Bailey LL. Right ventricular outflow tract reconstruction using a Goretex membrane monocusp valve in infant animals. ASAIO J. 2000;46(5):553-5.

[20] Yamagishi M, Kurosawa H. Outflow reconstruction of tetralogy of Fallot using a Gore-Tex valve. Ann Thorac Surg 1993;56:1414-6.

[21] Turrentine MW, McCarthy RP, Vijay P, McConnell KW, Brown JW. PTFE monocusp valve reconstruction of the right ventricular outflow tract. Ann Thorac Surg 2002;73(3):871-9.

[22] Chan KC, Fyfe DA, McKay CA, Sade RM, Crawford FA. Right ventricular outflow reconstruction with cryopreserved homografts in pediatric patients: intermediate-term follow-up with serial echocardiographic assessment. J Am Coll Cardiol 1994;24:483-9.

[23] Lecompte Y, Neveux JY, Leca F, Zannini L, Tu TV, Duboys Y, Jarreau MM. Reconstruction of the pulmonary outflow tract without prosthetic conduit. J Thorac Cardiovasc Surg 1982;84:727-33.

[24] Nomura F, Kadoba K, Ichikawa H, Akedo H, Matsuda H. Direct anastomosis of pulmonary artery-to-right ventricular outflow for correction of tetralogy of Fallot with pulmonary atresia. Ann Thorac Surg 1996;62:1199-202.

[25] Lacour-Gayet F, Serraf A, Komiya T, Sousa-Uva M, Bruniaux J, Touchot A, Roux D, Neuville P, Planche C. Truncus arteriosus repair: influence of techniques of right ventricular outflow tract reconstruction. J Thorac Cardiovasc Surg 1996;111:849-56.

Appendix A. Conference discussion

Dr S. Daebritz (Munich, Germany): I have just two questions. Obviously, the ePTFE grafts did very well. What was your mean follow-up for these?

The other question: did you use any anticoagulation therapy post-operatively, particularly if you inserted these ePTFE grafts in neonates where you oversized. Probably not all leaflets need to open because of the small stroke volume so that there might be an increased risk of thrombosis.

Dr Koh: All patients are administered warfarin plus low dose of antiplatelet agent for at least one year. For infant, our preferred procedure has been non-conduit repair since 1992. There is no infant having ePTFE tri-leaflet conduit in this series.

And please repeat the first question

Dr Daebritz: It was only about the mean follow-up of the ePTFE graft.

Dr Koh: Mean follow-up of ePTFE tri-leaflet conduits is 2 or 3 years. From 1996, we employed ePTFE leaflets.

Dr R. Deac (Targu-Mures, Romania): I have two questions. First one is, what was the reason to use equine pericardium as the material. And during the utilization have you seen calcification?

Dr Koh: At first we used porcine pericardium for the leaflet material. Next generation was equine pericardium and third generation was bovine pericardium. We were disappointed at the degenerative change of porcine pericardium; but equine pericardium as well as bovine pericardium had similar result, so we abandoned the use of glutaraldehyde-fixed pericardium and employed ePTFE sheet for the leaflet material.

Dr Deac: And the second question, if I may, have you seen in the long-term results in the conduit a kind of neointima deposition, a thickening of the conduit?

Dr Koh: Yes, thickening formation was found in all cases to some extent, but main cause of conduit obstruction was calcified leaflets.

Dr H. Lindberg (Oslo, Norway): I would like to ask you a question about what was the quality of the ePTFE leaflets, is that 0.1, 0.4? And what is the porosity of those leaflets?

Dr Koh: We employ 0.1 mm ePTFE sheet.

Dr Lindberg: With no porosity? Because the 0.1 Gore-Tex that we have available in Europe is no porosity, in contrast to the cardiovascular patches which has 50 micron porosity.

Dr Koh: I don't understand your question. You're asking about the thickness of the leaflet?

Dr Lindberg: And if they are expanded. Because that 0.1 in Europe is not expanded, it's a solid membrane.

Dr Koh: We use expanded one.

Dr Edmunds: You're talking about the porosity?

Dr Lindberg: The usual porosity of the Gore-Tex membrane is 50 microns and the surgical membrane that is available in Europe is no porosity at all.

Dr Koh: Gore-Tex membrane we usually used for pericardial patch.

Dr V. Tsang (London, United Kingdom): I noticed you have gone through three different types of animals for your handmade valve. As we know, the only thing constant in life is change. What would you use conduit wise for your reoperations?

Dr Koh: Indication for the operation?

Dr Tsang: No. What conduits are you going to use for your reoperations?

Dr Koh: Are you asking about the kind of conduit in reoperation?

Dr Tsang: Yes.

Dr Koh: There were 68 reoperations in this series and half of them underwent anterior patching as described by Dr Danielson. The other patients underwent second implantation of tri-leaflet handmade conduit.

EJVES Extra 9, 116–117 (2005)
doi:10.1016/j.ejvsextra.2005.02.024, available online at http://www.sciencedirect.com on SCIENCE DIRECT®

SHORT REPORT

Successful *In situ* Graft Replacement and Omentopexy for Abdominal Aortic Stent Graft Infection after Repeated Placement for Endoleak

H. Matsuda,* H. Ogino, H. Sasaki, K. Minatoya, T. Yagihara and S. Kitamura

Department of Cardiovascular Surgery, National Cardiovascular Center, Suita, Osaka, Japan

The infection of an endoluminal stent graft (ESG) for AAA repair is unusual. We report the successful management of this serious complication with an open in situ *graft replacement and omentopexy.*

Report

A 77-year-old male was admitted for persistent fever and lumbago. He had a secondary stent graft placement for type III endoleak 2 months before this admission. The initial placement of a custom-made stent graft for his AAA had been done 4 years previously. He also had a history of coronary artery disease treated by repetitive catheter interventions and a carotid artery stenosis. His WBC count was 13,400/mm^3 and CRP was 25 mg/dl. A CT scan showed a tear of the posterior wall of the aneurysm with no extravasation of contrast. After a week of antibiotic therapy, WBC decreased to 8540/mm^3 and CRP to 13.28 mg/dl, however, his symptoms did not improve. CT showed abscess formation in the left psoas muscle, and FDG-PET showed marked accumulation behind the AAA (Fig. 1).

Through a midline laparotomy, the expansive but not pulsatile AAA was exposed. From the left psoas muscle, turbid pus discharged. After suprarenal aortic clamp, the aneurysm sac was incised. Massive muddy, but not bloody, discharge was encountered (Fig. 2). A defect in the posterior wall, 20 mm in diameter, was found. The stent grafts were removed and the aorta was divided just below the renal arteries. The abdominal aorta was reconstructed with 16×8 mm bifurcated ePTFE graft and the aneurysm wall was resected completely. The duration of the suprarenal aortic clamp was 37 min. After the vigorous lavage with 30 l of normal saline, the graft was wrapped with an omental flap pedicle.

His symptoms improved, and WBC and CRP returned to normal within a few weeks. The culture of the psoas abscess and the AAA revealed *Bacillus cereus*. He was put on antibiotics for 6 months. He showed no sign of infection for 1 year after the surgery.

Discussion

The rate of ESG infection varies: 0.55% at 7 years among 362 patients[1] and 3.5% at 52 months among 144 patients.[2] Fiorani *et al.* reported from an international questionnaire that ESG infection rate (0.4%) was lower than for conventional open repair.[3] The cause of ESG infection is controversial. The delivery sheath may prevent the direct contact between ESG inside and the skin, however, ESG within the aorta has no protection against bacterial contamination until the neointimal covering.[3]

Jackson *et al.* reviewed 18 cases of abdominal ESG infection and eight of them were complicated with graft-duodenal fistula.[4] The exact cause or risk factors of ESG infection are still to be investigated.[3] In this case, repeated stent graft procedures which were performed in the radiological suite might be the positive factors for ESG infection.[1,3]

Extra-anatomical bypass with aortic stamp or *in situ*

*Corresponding author. Hitoshi Matsuda, MD, Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan. Tel: +81-6-6833-5012; Fax: +81-6-6872-7486.
E-mail address: hitmat@hsp.ncvc.go.jp

1533-3167/000116+02 $35.00/0

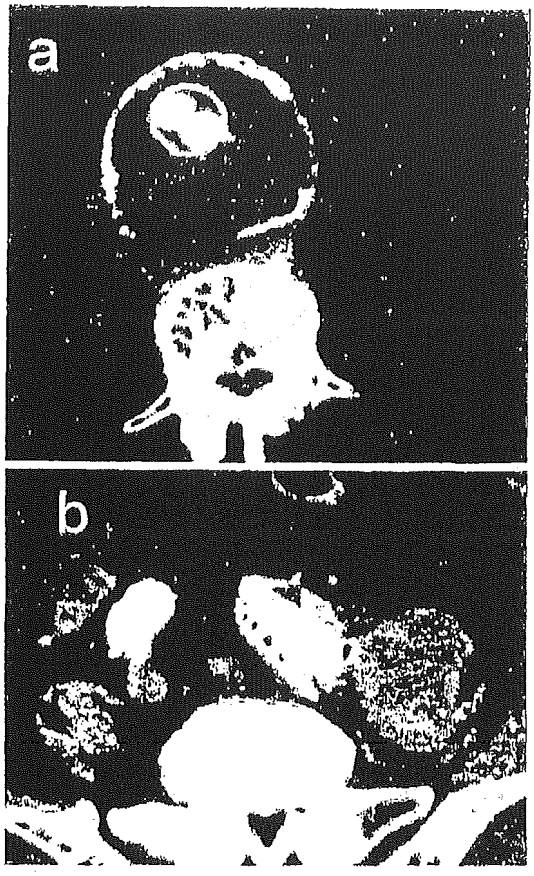

Fig. 1. Preoperative CT showed a tear of the posterior wall (a) and an abscess in the left psoas muscle (b). FDG-PET showed marked accumulation behind the AAA (c).

graft replacement is a difficult choice for this serious complication. Fiorani *et al.* reported the lower mortality with *in situ* graft replacement and pointed the possibility that the extra-anatomical bypass was indicated for more severely diseased patients.[3] We chose to treat infected

Fig. 2. Endoluminal stent graft was surrounded with massive muddy, but not bloody, discharge.

abdominal aorta with an *in situ* graft replacement, of which the proximal anastomosis can be performed with the same margin as for the aortic stump, complete debridement of the infected tissue, and omentopexy. The proximal end of stent graft is usually located more proximally than the open graft anastomosis, clamping of the suprarenal aorta may be more often needed for the stent graft infection than the usual infectious aortic aneurysm.

References

1 Dattilo JB, Brewster DC, Fan C, Geller SC, Cambria RP, LaMuraglia GM *et al.* Clinical failures of endovascular abdominal aortic aneurysm repair: incidence, causes, and management. *J Vasc Surg* 2002;35:1137–1144.
2 Schlensak C, Doenst T, Hauer M, Bitu-Moreno J, Uhrmeister P, Spillner G *et al.* Serious complications that require surgical interventions after endoluminal stent-graft placement for the treatment of infrarenal aortic aneurysms. *J Vasc Surg* 2001;34:198–203.
3 Fiorani P, Speziale F, Calisti A, Misuraca M, Zaccagnini D, Rizzo L *et al.* Endovascular graft infection: preliminary results of an international enquiry. *J Endovasc Ther* 2003;10:919–927.
4 Jackson MR, Joiner DR, Clagett GP. Excision and autogenous revascularization of an infected aortic stent graft resulting from a urinary tract infection. *J Vasc Surg* 2002;36:622–624.

Accepted 22 February 2005

今日の問題

冠動脈バイパス手術の進歩

The continuing evolution of coronary bypass surgery

中嶋 博之 NAKAJIMA Hiroyuki
小林 順二郎 KOBAYASHI Junjiro
田鎖 治 TAGUSARI Osamu
北村 惣一郎* KITAMURA Soichiro

はじめに

近年，冠疾患は本邦においても著しく増加し，2002年の単独冠動脈バイパス手術(CABG)は21,000例を越え，その手術成績も向上して，手術死亡率は2％となってきた．一方，患者の重症化や高齢化により，人工心肺を使用することで，脳梗塞等の術後合併症をきたす可能性の高い患者も増加している．本稿では，近年の冠動脈バイパス手術の進歩について，OPCABの導入，動脈グラフトの多様，低侵襲手術，それぞれの観点から考察し今後を展望する

I. OPCABの標準化

Sabistanらにより1962年に施行されて以来，OPCAB(off-pump coronary artery bypass grafting)の歴史は比較的長いが，人工心肺・心筋保護技術の発達により，近年までは適応がきわめて限定され，人工心肺不適例で，前下行枝や右冠動脈へのバイパスのみを対象としていた．しかしながら，近年，さまざまなdevice等の進歩により，病変部位によらず，OPCABが可能となってきた．

吻合中，心臓を脱転した際の血行動態の安定性を得るために，かつては困難とされた回旋枝領域に対してもdeep pericardial traction sutureや，suction deviceを用いて心尖を挙上する方法により比較的容易にアプローチすることが可能となってきた．targetとなる冠動脈枝の視野展開にも格段の進歩がある．吻合部位をsuction typeのstabilizerを用いて固定し，rubber loop，CO2 blower，intracoronary shuntを必要性に応じて使用することで，安定した良好の視野が得られる．とくにOctopus 4など新しいのstabilizerではprofileが低く改良されており，近接した冠動脈のsequential吻合や，狭小冠動脈に対しても視野が良好に保たれ，高い開存率を期待することができる[1][2](図1)．

OPCABの成績についてはいまだ議論のあるところである．これまで一般的に，人工心肺，心停止下のCABGと比較して，挿管時間，ICU／入院期間や，出血量，輸血量の点ではOPCABにメリットがあると考えられてきた[3][4]．また，OPCABでは大動脈に対する手術手技を回避することができることから周術期の脳合併症の回避にも有効である可能性が高く，とくにハイリスクと考えられる症例については，人工心肺を回避することによりmortality rateを低下することができると期待されている[5]．腎，呼吸器合併症についてもOPCABが有利とされ[6]，実際，アメリカ

国立循環器病センター心臓血管外科 *総長
Key words：冠動脈バイパス術，内胸動脈グラフト，低侵襲心臓手術，手術用ロボット

0433-2644/05/¥50/頁/JCLS

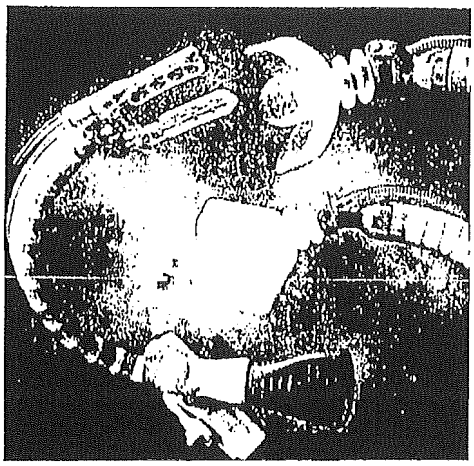

図1 Octopus 4, Starfish 2, およびUrchin Heart Positioner

国内でも冠動脈手術の20～25%がOPCABで施行され増加傾向にある．しかしながら，一方でoff-pumpとすることにより，技術的な問題からグラフト本数が減少し，開存率が低下し，revascularizationが不完全となり，結果として，遠隔成績が劣るのではないかという懸念があるのも事実である．

最近になりprospective randomized studyの成績も徐々に明らかとなってきている．当初，mortalityやperioperative strokeには差が認められず，輸血量，心筋逸脱酵素に関してのOPCABの優位性を認めたもの[7][8]，術後心房細動の発生率の違いを認めたものなど[9]，主要な手術合併症の頻度には有意差を認めないものの，わずかにOPCABに優位性があるとする報告が多い．しかし，Legareらは，挿管時間，ICU／在院日数，輸血量，早期合併症いずれもon-pump，off-pumpに差がなく，このなかで，OPCABでは末梢側吻合箇所数が少ない傾向を示しており，13%でon-pumpにconvertしたとしている[10]．Khanらは，手術合併症の発生には差がないものの，吻合箇所数に有意差があり，術後3ヵ月のグラフト開存率が全冠動脈領域で，とくに前下行枝においてはon-pump 100%に対し，off-pump 92%とOPCABが有意に低値であったとし，遠隔成績への影響が危惧されるとしている[11]．このように，最近はむしろOPCABの信頼性に疑問を投げかけるものも見られるようになってきたが，背景には，海外で全CABGに対するoff-pumpの割合が低いことがあると思われる．

当センターを含む国内多施設でのrandomized studyによればOPCABに習熟した5施設で，OPCABと人工心肺を使用した通常のCABGを比較する前向き無作為比較試験(JOCRI-study：Japanese Off-pump Coronary Revascularization Investigation-study)の早期成績をOPCAB群81例，人工心肺使用群86例についての検討によれば，術前の患者背景等に差は認められず，両群ともに手術死亡はなかった．OPCAB群，人工心肺使用群で，手術時間，最高CK-MB値，術後Neuron-Specific Enolase値，S-100蛋白値，無輸血率，入院医療費(保険請求額)で両群間に有意差を認め，OPCAB群で有意に良好な結果であった．OPCAB群，人工心肺使用群で，バイパス本数，開存率に有意差を認めなかった．

II. 全動脈グラフト多枝バイパスへ

動脈グラフトの使用は，内胸動脈による冠動脈バイパス術としてGoetzらにより1961年に施行され，また，Kolesovらにより1967年に初めて報告された．静脈グラフトの開存率やthrombosis，intimal hyperplasia，atherosclerosisなど，いわゆるsaphenous vein graft diseaseが明らかとなり，それとともに，長期にわたる内胸動脈グラフトの優位性の報告が相次ぎ，内胸動脈の使用頻度は1970～80年代に飛躍的に増加し，内胸動脈—左前下行枝バイパスとその他の枝に対して静脈グラフトを用いるのが90年代の標準的術式となった．

内胸動脈グラフトは長期開存性にすぐれ，atherosclerosisの発生がなく，この使用により生命予後を改善すると広く認められ，本邦でも同様の結果が報告されている[12]．さらに，両側の内胸動

脈の使用により，より良好な遠隔期成績が期待することができる．このため，可能なかぎり動脈グラフトを多用し完全血行再建を目指す術式が，現在の標準的な術式といえる．当センターでも，70～75歳以下の症例では両側の内胸動脈を使用することとし，高齢者であってもfree graftとしては橈骨動脈を第一選択としている．橈骨動脈は内胸動脈と共通した特性を有し，早期から中期の開存率は，狭小冠動脈や，軽度狭窄の枝に対しても，内胸動脈と差がないとの報告もある．

動脈グラフトでは，内腔の血流にあわせて径を変化させるという独特の生理的性質がある．これは狭窄の度合いが軽度な冠動脈枝に対するバイパスは，流量が少ないことから，グラフトの径の狭小化をきたし，さらには閉塞にいたるとされている．また，このような機序による閉塞では，冠動脈病変の進行によりグラフトが再開通し再び機能を回復する可能性示唆する現象も報告され興味深い[13]．

当センターでは，OPCABのメリットを最大限に生かし脳合併症を回避すべく，橈骨動脈をcomposite graftとして使用するいわゆるaorta no-touch techniqueを適用している．最近のrandomized studyによれば，手術の安全性，バイパス開存率，心事故回避率などでの優位性が報告されるようになった[14]-[16]．これにより，大動脈石灰化が著明であったり脳障害のリスクが大きい血液透析患者や高齢者等適応の拡大に貢献している．しかしcomposite graftの欠点としては，ひとつは，血流の供給がすべて内胸動脈に依存するため，とくに片側内胸動脈での3枝バイパスなどでは，hypoperfusion syndromeの危険性がある．これは多くは内胸動脈のqualityとの関連があるとされている．そのため，内胸動脈や鎖骨下動脈をカテーテル造影やCT，MRIなどで術前評価を行うことにしている．また，harvest後や，吻合後に流量測定により確認している．これにより，当センターではOPCAB後にhypoperfusionが疑われるような症例は経験していない．Pumpを使用していないことも，心筋へのダメージを最小限とし心筋内の血管抵抗を上昇させないことにつながり，hypoperfusion syndromeを起こりにくくしているものと思われる．

もうひとつの欠点としては，composite graftとして多枝にまたがる複雑な血流路が新たに形成されるため，このcomposite graft内での血流分布が必ずしも定かではないことがあげられる．当センターでの検討によれば，全動脈グラフトによるOPCABでは良好な開存率が期待できるが，一方でcomposite graft内でのcompetitive flowは，75%狭窄の右冠動脈枝を含む場合と，末梢側吻合数の増加が有意に関連することが示されている[17]．この現象が遠隔期の予後やグラフトの開存性に与える影響については現時点では不明である．

また一方で，静脈グラフトに対する遺伝子導入は一部ですでに臨床応用されており，また，小口径血管グラフトについても今後の開発が期待される[18]．

III. 低侵襲手術の確立

小開胸下に吻合を行うMIDCABは，①LAD近位部のカテーテルインターベンション不適の複雑病変，②カテーテルインターベンション後の再狭窄例，③ハイリスク症例に対するhybrid治療の一部として，④左内胸動脈が温存された再手術例などが適応とされ[9]，対象となる患者はかなり限定されているものの，内視鏡補助による術式として比較的認知されている．小切開から直視下に内胸動脈を採取する手術方法が当初は行われたが，これには開胸器による展開を要し，肋骨の損傷や疼痛の原因ともなりえた[19]が，内視鏡下で，もしくは，ダヴィンチを用いて内胸動脈を剝離することにより，肋骨の損傷やtractionを回避できメリットは大きく[20]，患者の満足度も高い[21]．また，懸念される吻合のqualityについても，他の術式に増して十分な術野の確保の重要性が大きいが，最近のoff-pump手術の確立に伴うdeviceの革命的進歩により，吻合中の血行動態と冠動脈

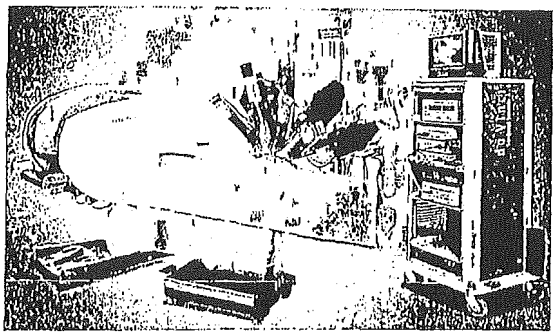

図2 Da Vinci Surgical System

の安定性は格段に向上している．正中切開を行わず胸腔鏡を用いて内胸動脈を採取することにより，縦隔炎などの重篤な合併症は回避することができ，また，疼痛などの点で一定の効果が得られることがわかってきた[21)22)]．

しかしながら，従来の胸腔鏡の鉗子類は可動域の制限が大きく精密な作業には限界があり，さらなるこの術式を発展のためには新しいdeviceの導入の必要性が指摘されていた．手術用ロボットとしてまず導入されたZeus Systemは，セットアップの容易さとボイスコントロールによるカメラアームを特徴としたが，これを用いたCABGでは，手術の安全性について問題はないものの，グラフトの開存性については必ずしも満足すべきものではなかった[23)24)]（図2）．

ダヴィンチはその特徴として，生理的振動の補正機能や術者の動きを最高5分の1まで縮小し鉗子に伝達することができ，EndoWristと呼ばれる人の手首をモデルとした7軸の可動性を有する左右アームと，高画質の3次元の立体画像により，緻密な手術手技を内視鏡的に行いえるとされ，低侵襲心臓手術のさらなる発展性が期待されている（図3）．ダヴィンチを用いての内胸動脈の剝離・採取にすることについては，確実性，安全性には概して問題はないようである．グラフトの損傷は通常手術へのconversionを必要とする事態ともなりえるが[25)]，Falkらの報告によれば，当初100～130分要した剝離時間が約15～20例の経験により60分前後に短縮されている．さらにその後40分にまで短縮されており，96%で採取に問題がなかったとしている[26)]．その他の報告でも，10～20例程度のlearning curveののちには40～60分以内に採取することが可能で手術時間への影響もさほど大きくない[25)27)28)]．

図3 ダヴィンチによる内胸動脈剝離

ダヴィンチを適用したCABGについては，Falkらは，胸骨正中切開心停止下のダヴィンチによるLITA-LAD吻合，ダヴィンチでのITA採取後のminithoracotomyより吻合を行うMIDCAB，完全内視鏡心停止下のCABGの3術式に分類している．完全内視鏡下CABGについては，その達成率は82%で，吻合は平均22分で行いえたとしている．開胸へのconvert率は18%であったが，その原因はLADの同定に関するもの2例（9%），ITA pedicleのねじれによるもの1例（4.5%）で，吻合手技に直接関連したものは吻合

図4 造影CTによるMIDCAB術前評価
LITA，LAD，肋間の位置関係，LADの走行の把握に有用である．

部出血の1例(4.5%)で，いずれのconversionも初期の症例に集中していると述べている[13][26]．Kappertらは，ダヴィンチ装置を用いた完全内視鏡下のCABG 29例のうち，開胸へのconvertはITA損傷の1例で，吻合時間はoff-pumpでも約30分で行いえるとしている．同施設でのすべての完全内視鏡下CABG 57例の経験でもLADの石灰化，筋肉内走行，不十分なstabilizationなどがconversionの原因となっている[25][27]．またDoganらの報告でも，初期のconversion率は22%ながらも25例以降のconversion率は5%となっている．冠動脈枝の同定が困難な症例があるが，これに対しては，CTによる術前評価により心室壁内走行や冠動脈の石灰化を術前に診断することによりconversionを回避し完全内視鏡下のCABGを行いえたとしている(図4)．また一方で，創の合併症はないものの，右冠動脈に対する吻合中の血行動態の悪化によるconversionや蘇生処置を要する重篤な合併症も発生している[25]．いずれの手術成績も，ダヴィンチそのものの限界を示しているものではない．

当センターにおいても，第2，4，6もしくは3，5，7肋間にポートを設置し，ダヴィンチで内胸動脈を採取した後に第4もしくは5肋間開胸での吻合を行う術式を，2004年9月より導入した．2005年1月現在4例に施行しているが，65～90分で十分な長さのグラフトを採取することができ，術後の造影からも，剝離の範囲や枝の処理は適切に行いえたと考えている．今後，内胸動脈の採取の症例数を重ね，装置に習熟し安全性を確立した後には，当施設においてもより低侵襲でのCABGを目指し，最終的には完全内視鏡下のoff-pump CABGへの発展や他疾患への適用も視野に入れており，現在はその初段階と位置づけている．

IV．当センターでの現状と今後の展開

これまで，当センターにおいて冠動脈バイパス術に関しては，すでに2000年にはoff-pumpにてCABG症例の98%を施行できるまでになっており[1]，on-pump CABGへのconversionは1～2%に過ぎない．グラフトの早期開存率も，以前と全く遜色はない[17][30]．また今後，Roboticsの導入とともに，バイパス術における末梢吻合や大動脈－free graftの自動吻合，U-clipのようなsuture deviceやdrug eluting stentとのhybrid治療など，新たなconceptやdeviceの適用がそのbreakthroughとなりえる．また，血管再生，心筋再生を目的とした細胞移植との合併手術も導入している．低侵襲手術においては，単に皮膚切開の大きさのみでなく，ハイリスク患者にも適用すべく手術リスクをより軽減し，遠隔成績をcompromiseしない術式の改良と適切な症例の選択が重要であると考えられる．

文 献
1) Kobayashi J, Tagusari O, Bando K, et al: Total arterial off-pump coronary revascularization with only internal thoracic artery and composite radial artery grafts. Heart Surg Forum 6: 30-37, 2002.
2) Matuura K, Kobayashi J, Taguasri O, et al: Rationale for off-pump coronary revascularization to small branches.