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Usefulness of percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis after surgery for CHD

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Abstract

Coronary artery involvements occur rarely both during cardiac repair and in the late period after surgery, and it may result in myocardial ischaemia and infarction. We present six cases who underwent percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis in the late period after surgery. The patients included four boys and two girls. Post-operative states involving anomalous origin of the left coronary artery from the pulmonary artery and d-transposition of the great arteries were observed in two patients each. Two patients with univentricular heart had coronary artery injuries during surgery. The age at the angioplasty ranged from 1 month to 14 years, with a median of 3 years. The interval from the operation to angioplasty ranged from 37 days to 14 years (median 8 months). The interval from the angioplasty to follow-up coronary angiography ranged from 2 months to 14 years (median 11 months). The follow-up period ranged from 2 months to 20 years (median 8 years). One patient underwent a stent implantation because of post-procedure recoil. Coronary artery stenosis improved immediately after procedure in the six patients without complication, and restenosis occurred post-procedure in one patient. Five patients had no cardiac events. Although the angioplasty's initial effect may not be dramatic, it can improve late after the procedure. It was considered that the optimal balloon-reference vessel ratio to obtain a minimal effective lumen diameter was about 1.0. Angioplasty post-surgery for CHD in children was feasible and without complications.

Introduction

Coronary artery involvements occur rarely both during cardiac repair and in the late period after surgery for CHD. Coronary artery stenosis can decrease the ventricular ejection fraction, and it can affect the prognosis after surgery. On the other hand, proximal stenosis adjacent to the orifices of the coronary arteries after surgery may occur after arterial switch operation for d-transposition of the great arteries.[1–3] Coronary artery stenosis often progresses post-operatively and may result in myocardial ischaemia and infarction. In such cases, coronary artery revascularization for coronary artery stenosis is needed. Either coronary artery bypass grafting or percutaneous transluminal coronary intervention for coronary artery stenosis after surgery for CHD has also been performed in some patients. However, there is little information about percutaneous transluminal coronary intervention for children after cardiac repair. Therefore, here we report on percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis in six patients who underwent a procedure after cardiac repair for CHD.

Patients

Coronary artery stenosis after coronary artery revascularization for anomalous origin of the left coronary artery (ALCAPA)

Two patients who had undergone coronary artery revascularization with Takeuchi method for anomalous origin of the left coronary artery underwent percutaneous transluminal coronary balloon angioplasty postoperatively. A-1-month-old girl underwent balloon angioplasty for severe coronary artery stenosis during the reconstruction of the left main trunk 44 days after cardiac repair (Table 1). Leakage from the baffle of the reconstructed coronary artery to the pulmonary artery at the anastomosis was detected, and moderate mitral regurgitation was also found. Her body weight was 4 kg, and a 4-Fr sheath was passed through the right femoral artery. The diameter of the balloon catheter was 3.0 mm, and it was inflated for 50 s to a pressure of 8 atm during the first inflation. When the balloon was inflated in the target vessel, ST-T changes were not detected on the 12-lead electrocardiogram. The diameters of the most stenotic segment

Table 1. Characteristics of patients with PCBA for coronary artery stenosis after surgery

Patient	1	2	3	4	5	6
Gender	female	female	male	male	male	male
Diagnosis	ALCAPA	ALCAPA	UVH	UVH	TGA	DORV
Target vessel	LMT	LMT	RCA	LMT	LMT	LAD
Age at surgery	1 month	11 years	1 year	4 years	7 months	6 days
Age at PCBA	2 months	11 years	2 years	4 years	11 years	14 years
Pre PCBA 99mTcMPI	not done	mild PD	PD (+)	PD (+)	mild PD	mild PD
Anethtesia	General	Local	General	General	Local	Local
Most stenotic diameter (mm)	0.3	0.5	0.6	0.3	0.7	0.7
Reference diameter (mm)	1.9	5.1	3.8	2.7	3.1	3.4
Balloon diameter used (mm)	3	4	2	2.75	3	2.25
Ratio of reference diameter/	1.6	0.8	0.5	1	1	0.7
balloon diameter						
Most stenotic diameter	2	2.2	2.9	2.9*	3	3
after PCBA (mm)						
Late period after PCBA						
Age at follow-up CAG	4 months	17 years	18 years	9 years	21 years	15 years
Most stenotic diameter (mm)	0.5	2	2.9	2.9	2.8	2.8
Re-stenosis	+	none	none	none	none	none
Post PCBA 99mTcMPI	none	mild PD	none	PD (+)	none	none
CFR measured by TTE	not done	4.0	not done	not done	3.8	2.1

ALCAPA = anomalous origin of left coronary artery from pulmonary artery; CAG = coronary angiogram; PCBA = percutaneous transluminal coronary balloon angioplasty; UVH = univentricular heart; TGA = d-transposition of the great arteries; DORV = double outlet right ventricle; LMT = left main truncus; RCA = right coronary artery; LAD = left anterior descending artery; CAS = coronary artery stenosis; PD = perfusion defect; MPI = myocardial perfusion imaging; CFR = coronary flow reserve; TTE = transthoracic echocardiography; N/A = not available.
*stent implantation.

and the post-stenotic segment of the left coronary artery were 0.3 mm and 1.9 mm, respectively. There were no complications. However, the degree of the baffle leakage gradually increased on two-dimensional echocardiography. Two months later, the coronary angiogram showed restenosis of the reconstructed left main coronary artery, and mitral regurgitation was severe. Therefore, she underwent a repair of the baffle leakage and mitral valve replacement.

An 11-year-old girl underwent percutaneous transluminal coronary balloon angioplasty because of severe coronary artery stenosis at the left main trunk reconstruction 37 days after the cardiac repair. The diameter of the balloon catheter was 3.0 mm, and the balloon was inflated to a pressure of 8 atm and 14 atm during the first and second inflations, respectively. The third inflation was to 6 atm with a balloon diameter of 4.0 mm. The diameters of the most stenotic part of the reconstructed left coronary artery improved from 0.7 mm to 1.9 mm (Figure 1). There were no complications. In both the pre-operation and post-operation, mild hypoperfusion was detected on the anteroseptal wall of the left ventricle in the ^{99m}Tc myocardial perfusion imaging. After the angioplasty, no ST-T changes were detected during treadmill testing. On selective coronary angiograms 6 months after the percutaneous transluminal coronary balloon angioplasty, there was no restenosis. Aspirin was stopped at the age of 15 years old. She had no cardiac events with no medication for 18 years after the procedure, and she delivered two children with no complications.

Management of stenosis due to coronary artery injury during surgery

A 19-month-old boy who required an anastomosis for a lacerated right coronary artery during a bidirectional Glen procedure at the age of 10 months for univentricular heart underwent percutaneous transluminal coronary balloon angioplasty for severe coronary artery stenosis. He had undergone Fontan procedure at the age of 17 months. However, he developed protein-losing enterocolitis after Fontan procedure. Although segment 1 of his right coronary artery was repaired during the operation, the stenosis progressed to 90% in the late period. Dipyridamole-loaded electron beam myocardial perfusion imaging showed a perfusion defect in the ventricle. The diameter of the balloon catheter was 2.0 mm, and the balloon was inflated to a pressure of 8 atm and 16 atm during the first and second inflations, respectively. The diameters of the most stenotic segment and the post-stenotic segment of the right coronary artery were 0.6 mm and 3.8 mm, respectively. The diameter of the balloon catheter was 2.0 mm, and it was inflated for 40 s to a pressure of 8 atm during the first inflation. When the balloon was inflated in the target vessel, inversion of T waves in leads $V_{1\text{-}4}$ was detected on the 12-lead electrocardiogram. The second inflation was performed for 60 s at a pressure of 16 atm. The degree of stenosis improved from 77 to 41%, immediately after the procedure (Figure 2). The balloon angioplasty was successful without any complications. Aspirin as an antiplatelet therapy had

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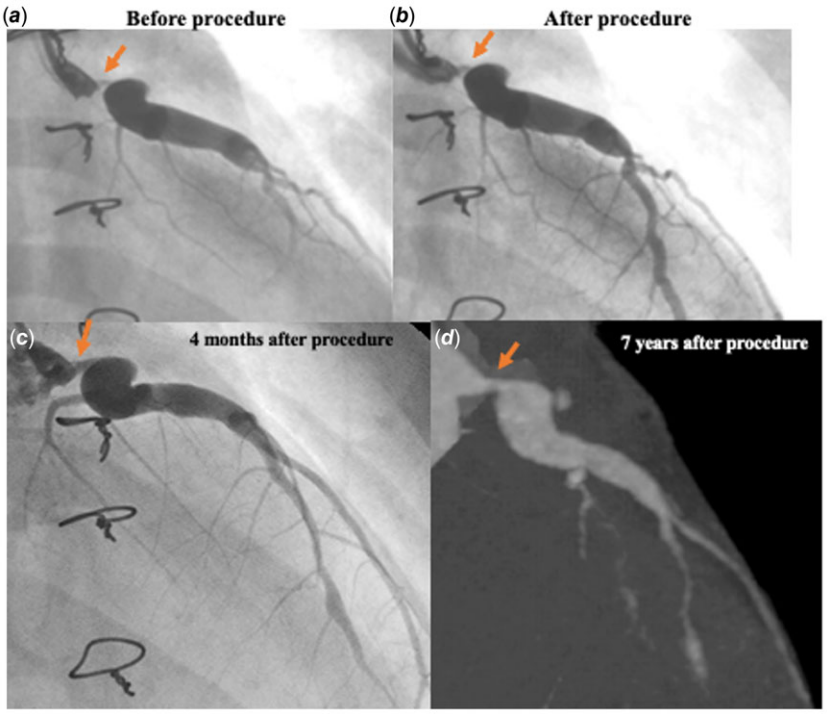

Figure 1. Left coronary angiograms before and after procedure (Patient 2). (***a***) Before procedure. (***b***) After procedure. Immediately after the procedure, the most stenotic diameter became from 0.7 to 1.9 mm. (***c***) Four months after procedure. (***d***) Computed tomography angiogram, 7 years after procedure.

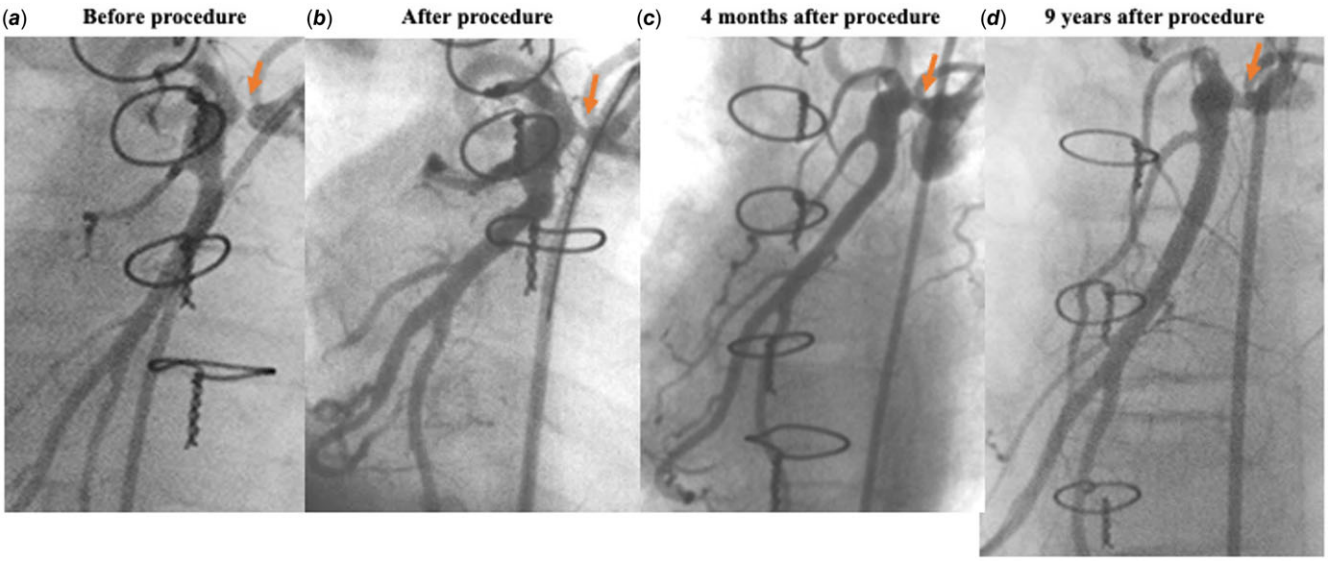

Figure 2. Right coronary angiogram before and after procedure (Patient 3). (***a***) Before procedure. (***b***) After procedure. Immediately after the procedure, the most stenotic diameter became from 0.6 to 2.0 mm. (***c***) Four months after procedure. (***d***) Nine years after procedure.

been taken before the procedure. The degree of stenosis improved during the late period. His hypoalbuminemia due to protein-losing enterocolitis also improved.

A 4-year-old boy who had had ventricular dysfunction due to injury to the left main coronary artery during a Fontan procedure for univentricular heart underwent a stent implantation for severe coronary artery stenosis. There were severe perfusion defect on ^{99m}Tc myocardial perfusion defect. The diameter of the balloon used was 2.0 mm during the first procedure and 2.5 mm during the second procedure, respectively. However, recoil was found after procedures. Therefore, a stent implantation with a Xience Alpine (2.75 mm) was performed. The diameter of the stenosis increased from 0.3 to 2.9 mm after the procedure (Figure 3). Although there were no complications during the procedures, his heart failure worsened immediately after the procedure because of the invasiveness of the procedure with general anesthaesia. His condition improved with intravenous administration of a phosphodiesterase III inhibitor. Six months after the procedure, his left ventricular ejection fraction on ^{99m}Tc myocardial perfusion imaging improved from 31 to 42%. No re-stenosis was detected on the coronary angiogram at the age of 9-year-old.

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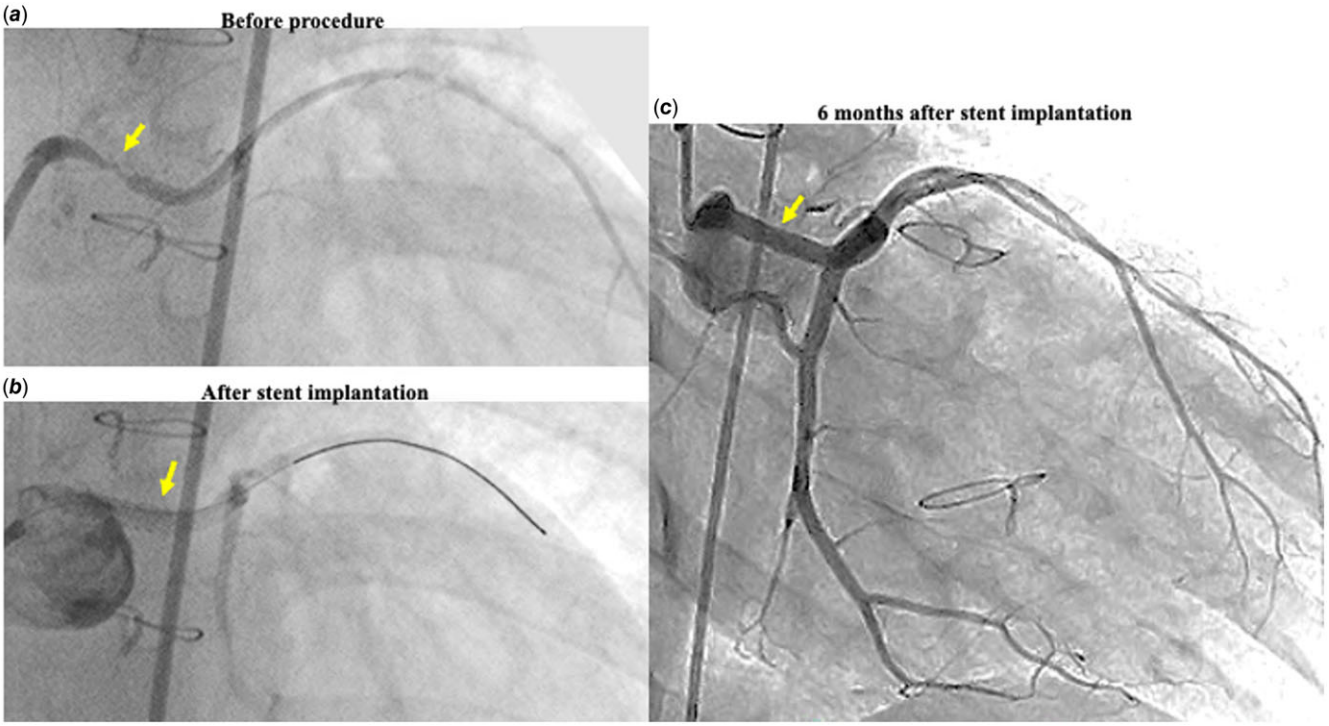

Figure 3. Left coronary angiogram before and after the stent implantation (Patient 4). (***a***) Before procedure. (***b***) After the stent implantation, immediately after the procedure, the most stenotic diameter became from 0.3 to 2.9 mm. A stent was implanted because of recoil after PCBA. (***c***) Six months after stent implantation.

Coronary artery stenosis after arterial switch operation

Two patients underwent percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis at the ages of 11 years and 14 years-old, respectively, during the late period of more than 10 years after arterial switch operation. They had had no symptoms before balloon angioplasty. The stenosis rates in both patients improved from 81% to 45% and 80% to 54%, respectively, immediately after. No restenosis was found, and the stenosis rate improved to about 30% late after balloon angioplasty. Although the effect of balloon angioplasty immediately after may be small, the rate of stenosis can improve late after balloon angioplasty. The optimal balloon-reference vessel ratio to obtain the effective minimal lumen diameter was 1.5.

An 11-year-old boy with transposition of the great arteries had undergone an arterial switch operation at 7 months of age, following a previous pulmonary artery banding. His coronary arteries were Shaher I type. Exercise-loaded ^{99m}-Tc-tetrofosmin myocardial perfusion imaging showed hypoperfusion on the basal anterior and anterolateral walls of the left ventricle. The diameters of the most stenotic vessel and the post-stenotic vessel in the left coronary artery were 0.7 mm and 3.1 mm, respectively. The diameter of the balloon catheter was 3.0 mm, and the balloon was inflated over 50 s to a pressure of 8 atm during the first inflation. When the balloon was inflated in the target vessel, transient elevation of T waves in leads $V_{1\text{-}5}$ on the 12-lead electrocardiogram was detected. The balloon was finally inflated for 50 s to a pressure of 13 atm. The balloon angioplasty was successful without any complications. In the coronary angiogram 10 years later, the diameter of the most stenotic portion was dilated to 2.8 mm. He has had no symptom for 35 years since the arterial switch operation and coronary balloon angioplasty.

The second patient was a 14-year-old boy who had undergone arterial switch operation at 6 days old. He had undergone right ventricular outflow tract reconstruction at 6 years of age. His coronary arteries were Shaher 2A type. A selective coronary angiogram at 13 years of age showed severe coronary artery stenosis of the left anterior descending artery. Dipyridamole-loaded ^{99m}-Tc-tetrofosmin myocardial perfusion imaging showed a perfusion defect on the antero-lateral wall of the left ventricle. The diameters of the most stenotic segment and the post-stenotic segment of the left anterior descending artery on the coronary angiogram were 0.7 mm, and 3.4 mm, respectively. Before the angioplasty, it was confirmed that the pulmonary artery did not compress the left anterior descending artery by dual-source computed tomography. Intravascular ultrasound after intracoronary administration of nitroglycerin revealed severe intimal thickening at the stenosis of the left anterior descending artery, and the diameter of the most stenotic site was 2 mm. The diameter of the balloon catheter was 2.25 mm, and the balloon was inflated for 18 s to a pressure of 6 atm during the first inflation. Finally, the diameter of the balloon was 3.0 mm, and it was inflated for 60 s to a pressure of 14 atm. The stenosis improved from 80% to 54% immediately after procedure. Percutaneous transluminal coronary balloon angioplasty was successful without any complications. Aspirin as an antiplatelet therapy was taken before the procedure. The stenosis rate improved to 23% 8 months after percutaneous transluminal coronary balloon angioplasty. The diameter of the left anterior descending artery orifice was dilated to 2.8 mm. The coronary flow reserve in the left anterior descending artery on

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adenosine triphosphate-loaded transthoracic echocardiography was increased from 1.6 to 2.1.

Discussion

We have seen some adverse effects due to coronary artery stenosis after cardiac repair for CHD, especially after coronary artery reconstruction. Coronary artery stenosis might be a cause of death immediately after repair in some cases, although it is difficult to clarify its prevalence. Coronary artery stenosis can also become the cause of death after CHD during the late period, and the coronary artery stenosis is usually asymptomatic until a cardiac event. Coronary artery stenosis after repair of CHD can be discovered unexpectedly when a post-operative evaluation is done. On the other hand, coronary artery stenosis can often be found as the cause of ventricular dysfunction after surgery. A reduced ventricular function after intracardiac repair can become fatal or lead to a poor prognosis in patients during the late period. Either myocardial ischaemia or infarction can affect ventricular function, and they often induce fatal cardiac events.

Therefore, we evaluate myocardial ischaemia after surgery by dipyridamole-loaded ^{99m}-Tc-tetrofosmin myocardial perfusion imaging and electrocardiogram. We perform cardiac catheterisation to evaluate the post-operative state and coronary artery stenosis, when ventricular dysfunction due to myocardial ischaemia is suspected. Furthermore, we follow the post-operative patients after cardiac repair by electrocardiogram or two-dimensional echocardiography each year or every other year. We evaluate myocardial ischaemia by these examinations, whether or not exercise is possible in each patient. When myocardial ischaemia is suspected in the examinations, coronary angiograms by dual-source computed tomography are performed to evaluate the degree of coronary artery stenosis.

Proximal stenosis just at the orifice of both coronary arteries can be found after arterial switch operation for transposition of the great arteries. Coronary artery stenosis often progresses within 6 months postoperatively, and it can lead to myocardial ischaemia and infarction. It is considered that the optimal balloon-reference vessel ratio to obtain an effective minimal lumen diameter is 1.0. Even if percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis is performed many years after arterial switch operation, it is feasible without any complications. Percutaneous transluminal coronary balloon angioplasty can also provide good results late after the procedure. The process leading to coronary artery stenosis after arterial switch operation is unknown, but the surgical procedure for coronary transfer could result in flow abnormalities leading to increased shear stress and progressive proximal eccentric fibrocellular intimal thickening.[3,4,5] One may speculate that maintaining the lumen of the coronary arteries that provides myocardial perfusion depends on the compression by the pulmonary arteries or the ascending aorta after cardiac repair. Imaging of the coronary wall by intravascular ultrasound in this patient demonstrated eccentric intimal thickening of the coronary artery wall typical of coronary artery stenosis after arterial switch operation, not like atherosclerosis plaque.[6] The findings were consistent with our pathological study showing that coronary artery stenosis developing within a few months after arterial switch operation was caused by intimal thickening in the coronary wall.[7]

The cause of coronary artery stenosis in paediatric patients after cardiac repair differs from atherosclerosis in adults. What is the optimal balloon size? A balloon-to-post-stenotic coronary diameter ratio of 1.1–2.0 has been advised in the previous reports.[8–10] The balloon-to-post stenotic vessel ratio was about 1.0 in our patients during the late period. It is believed that a balloon size equal to the diameter of the post-stenotic vessel is enough to obtain an effective laceration and compression of the intimal thickening. Re-stenosis after percutaneous transluminal coronary balloon angioplasty has not been described in the previous reports, and only one case occurred in our experience. Therefore, it seems that stenting in this population is not needed because it is not always progressive during the late period after balloon angioplasty with ageing. If there is recoil after balloon angioplasty, a stent implantation would be considered.

The usefulness of percutaneous transluminal coronary intervention in small patients may be controversial because the technique for the procedure and management of complications are more difficult than in adults. There are two major problems in small children with coronary artery stenosis. The target vessel is small, and the size of the guiding catheter suitable for the use of a larger balloon is also limited by the diameter of the femoral artery. Secondly, it is difficult to manage this in an emergency state due to complications during the procedure. It should be performed under general anesthaesia in small children. Even if they are asymptomatic immediately after the operation, severe coronary artery stenosis with ischaemia can develop with the physical growth with ageing. Therefore, the relief of coronary artery stenosis after intracardiac repair is very important. Coronary revascularization had three effects: reduction in the myocardial ischaemia, prevention of myocardial infarction, and improvement in the long-term prognosis. The indication for percutaneous coronary intervention for coronary artery stenosis should be decided based on the balance of the benefits and risks. It is considered that percutaneous transluminal coronary balloon angioplasty by skillful percutaneous coronary interventionists is less invasive and more useful in patients with severe coronary artery stenosis rather than coronary artery bypass grafting in some cases. CT angiography after the procedure can noninvasively evaluate any residual coronary artery stenosis during the follow-up, and it is useful.

Conclusion

Percutaneous transluminal coronary balloon angioplasty for coronary artery stenosis after coronary artery surgery for CHD in children was feasible without any complications and provided good late-term results for a long-life expectancy.

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Competing interests. The authors state that they have no conflict of interest.

Ethical standard. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional committee with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved in the ethics committee of the National cerebral and cardiovascular center of Japan (R20015-2).

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