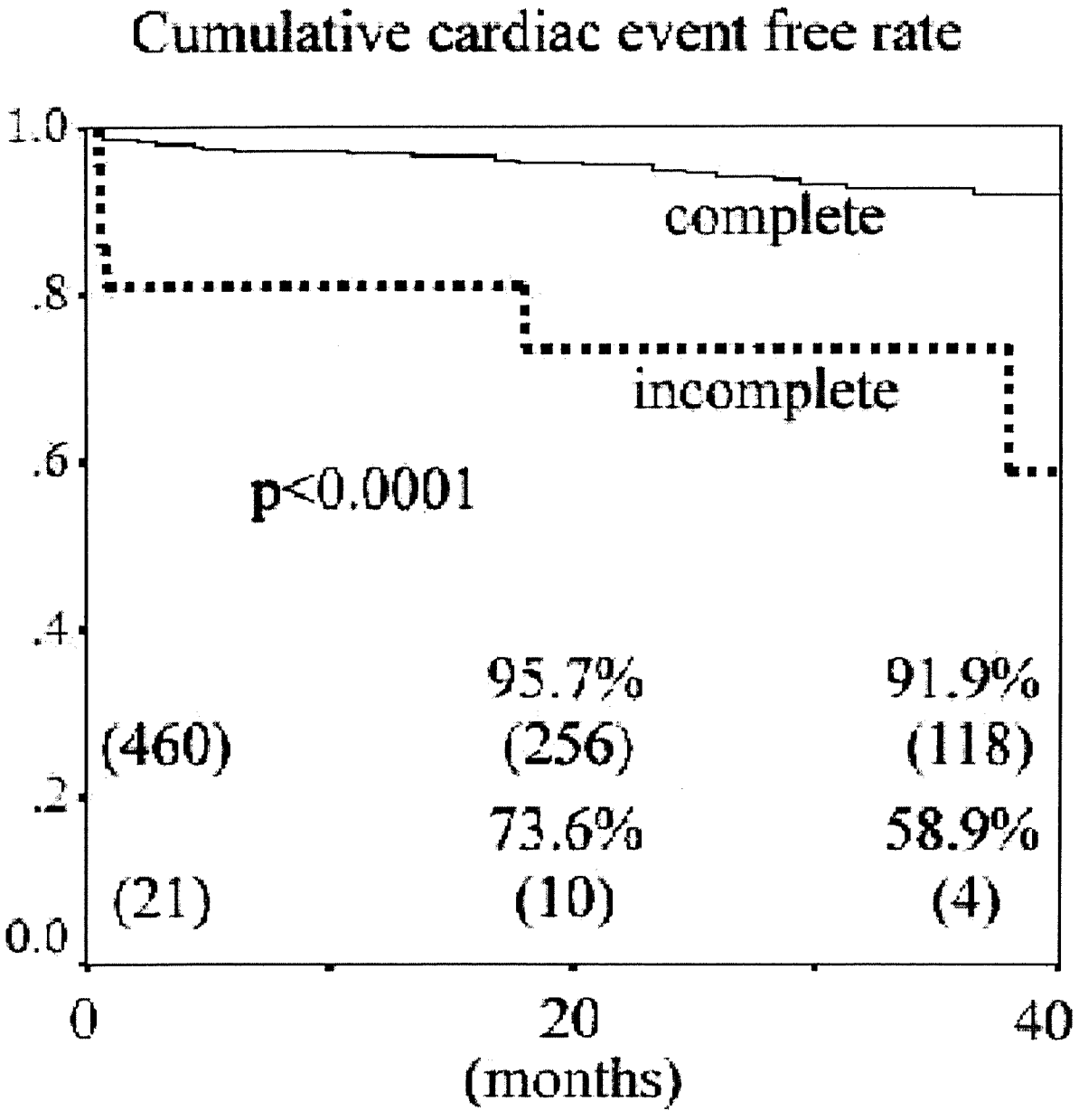
Table 4

Predictors of cardiac event in 481 patients with three-vessel disease

Variables	Hazard ratio	95% CI	p value
Univariate analysis			
Age	0.97	(0.94 - 1.001)	0.06
Female	0.81	(0.31 - 2.08)	0.65
Diabetes	0.51	(0.24 - 1.08)	0.08
Hypertension	0.70	(0.36 - 1.34)	0.28
Hyperlipidemia	1.44	(0.73 - 2.81)	0.29
Ejection Fraction < 40%	1.80	(0.92 - 3.52)	0.09
Bilateral in situ ITA	1.33	(0.67 - 2.60)	0.41
Early Period; Dec.2000~March 2003	3.28	(1.39 - 7.77)	0.007
Incomplete revascularization	5.27	(2.19 - 12.71)	<0.0001
Multivariate analysis			
Age	0.98	(0.95 - 1.01)	0.19
Diabetes	0.50	(0.24 - 1.07)	0.08
Ejection Fraction < 40%	1.69	(0.86 - 3.33)	0.13
Early Period; Dec.2000~March 2003	2.78	(1.18 - 6.57)	0.02
Incomplete revascularization	4.81	(1.98 - 11.65)	0.001

ITA; internal thoracic artery


Cumulative cardiac event free rate
1.0
.8
.6
.4
.2
0.0
complete
incomplete
p<0.0001
95.7%
(256)
73.6%
(10)
91.9%
(118)
58.9%
(4)
(460)
(21)
0
20
40
(months)

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CURRENT TOPICS REVIEW ARTICLE

Current status of coronary artery bypass grafting

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Abstract The number of cases of coronary artery bypass grafting (CABG) reached more than 21 000 in Japan in 2002, and the operative mortality decreased to less than 1%, including emergency operations. The annual number of CABGs in Japan declined 17% after 2003 to 18 000 cases in 2005 owing to unrestricted percutaneous coronary intervention (PCI) with drug-eluting stents. However, CABG is the best treatment for multivessel coronary artery disease based on the comparative data of PCI versus CABG. There have been two trends in CABG during the last decade. One is the widespread use of off-pump (OP) CABG, and the other is multiple coronary artery revascularization. In 2004 and 2005, approximately 60% of all isolated CABG procedures in Japan were performed without cardiopulmonary bypass. In a study of long-term outcomes comparing PCI with drug-eluting stents versus CABG with only arterial grafts, the latter was carried out in 52% of total cases and in 66% of OPCAB cases. OPCAB with multiple arterial grafts has become the standard CABG in Japan.

Key words Coronary artery bypass · Percutaneous coronary intervention

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Introduction

Coronary artery bypass grafting (CABG) performed with cardiopulmonary bypass (CPB) has become an established treatment for patients with coronary artery disease. The number of CABGs reached 21 000 cases in 2002, and the mortality associated with elective CABG became less than 1% according to the database of the Japanese Association for Thoracic Surgery. However, the annual number of CABGs declined 17% after 2003 to 18 000 cases in 2005 owing to the unrestricted percutaneous coronary intervention (PCI) with introduction of the drug-eluting stent (DES) in Japan. During the last decade, two major revolutions in CABG have been seen. One is the development of CABG without CPB, and the other is CABG with multiple arterial grafts. These new trends are much more advanced in Japan than in either North America or Europe. Here, I review the current status and future of CABG.

Comparison of CABG and PCI

CABG versus POBA
(Primary Old Balloon Angioplasty)

Since the 1980s, multiple randomized controlled trials (RCTs) on PCI versus CABG have been conducted.[1–4] The Emory Angioplasty Surgery Trial (EAST) showed an 8-year mortality of 17.3% in the CABG group compared with 21.7% mortality in the PCI group.[1] The relative mortality difference of 4.3% between PCI and CABG for patients with multivessel disease was not significant because of the small numbers of patients enrolled.[2] The largest RCT of CABG versus PCI was the Bypass Angio-

plasty Revascularization Investigation (BARI) trial from 1988 to 1991.[3] The 7-year mortality rate was significantly better in the CABG group (16.6%) than in the PCI group (19.1%), although the 15% difference occurred in the 7.3% of patients with multivessel disease who were most suitable for either PCI or CABG.[4] In many RCTs, including the BARI study, CABG was most favorable in diabetic patients.[5] Repeated revascularization was significantly higher in the PCI patients than in those who underwent CABG because of restenosis. A meta-analysis of nine RCTs studying CABG versus PCI in patients with multivessel disease revealed that survival was equivalent at 1 and 3 years, but the initial CABG group had significantly better 5- and 8-year survivals than the initial PCI group.[6]

CABG versus bare metal stents

Several RCTs of CABG versus PCI with bare metal stents (BMS) have been reported. The Arterial Revascularization Therapies Study (ARTS) was a highly PCI-friendly trial regarding enrollment.[7] Only 5% of the patients enrolled were very low risk: no previous PCI, no congestive heart failure, no recent myocardial infarction, no cerebrovascular disease, young age (mean 61 years), and good left ventricular (LV) function (mean LV ejection fraction 0.61). The 1-year mortality rates and major adverse cardiac and cerebral events rate were the same.[8] By 1 year, however, repeat revascularization was required more frequently in PCI patients (16.8%) than in CABG patients (3.5%). The 5-year mortality and major adverse cardiac and cerebral events rates were 7.1% and 13.5%, respectively, in the CABG group and 8.0% and 18.0% in the PCI group. At 5 years the repeat revascularization rate was 8.8% for the CABG patients and 30% for the PCI patients. There was a study bias in that one member of the board of this study was a vice president of Cordis, a division of Johnson & Johnson Company.[9]

The study called Coronary Angioplasty with Stenting versus Coronary Bypass Surgery in Multivessel Disease (ERACT II) revealed that the 30-day mortality was 0.9% in the stent group and 5.6% in the CABG group.[10] This high mortality of CABG was attributed to a relative delay of therapy in unstable patients. Because of this high early mortality in the CABG group, the 5-year mortality was better in the stent group (7.2%) than in the CABG group (11.6%). The 5-year major adverse cardiac and cerebral events rate was better in the CABG group (23.6%) than in the stent group (34.7%). The problems with CABG in the ERACT II study were a small surgical volume (<100 cases a year) in participating centers and low use of the left internal thoracic artery (LITA) (89% among patients who, on average, were 62 years of age).[11] The quality of surgical therapy in this study might have been poor.

The SoS trial in Europe and Canada demonstrated that repeated revascularization was significantly higher in the stent group than in the CABG group (21% vs. 6%: hazard ratio 3.85, $P < 0.0001$) at the 2-year median follow-up.[12] Although the incidence of death or Q-wave myocardial infarction was not different between the PCI and CABG groups, the cumulative deaths at a 2-year median follow-up were significantly higher in the stent group than in the CABG group (8 vs. 22 deaths: hazard ratio 2.91, $P < 0.01$). There was no further follow-up because the SoS study was funded by stent manufacturers.[9]

In addition to the RCTs, a large observational study from New York cardiac procedure registries from 1997 to 2000 analyzed 59 000 patients with multiple-vessel disease who underwent PCI with BMS or CABG.[13] At the 3-year follow-up, repeat revascularization was seven times higher in the PCI group (35.1% of PCIs vs. 4.9% of CABGs). In the case of three-vessel disease with a proximal left anterior descending artery (LAD) lesion, the hazard ratio for CABG regarding 3-year adjusted mortality compared to that of PCI was 0.64 in all patients, 0.69 in diabetic patients, and 0.68 in patients with poor LV ejection fraction (LVEF) <0.40. In patients with two-vessel disease with a proximal LAD lesion, the hazard ratio of mortality was 0.75 in all patients, 0.71 in diabetic patients, and 0.64 in patients with poor LVEF <0.40. In 2000, according to the New York cardiac registries, PCI with BMS seemed not to be appropriate for multivessel coronary artery disease.

CABG versus drug-eluting stents

Coating stents with an antiproliferation drug inhibits intimal hyperplasia after PCI.[14] Commercially available sirolimus (CYPHER; Cordis Corporation, FL, USA) and paclitaxel (TAXUS; Boston Scientific, MA, USA) stents have been widely used. A meta-analysis of 11 RCTs of drug-eluting stents (DESs) versus BMSs demonstrated that the major adverse cardiac events rate of death, myocardial infarction, or target-vessel revascularization was 7.8% with DESs and 16.4% with BMSs; and the restenosis rate was 8.9% with DESs and 29.3% with BMSs. However, not a single trial demonstrated a mortality benefit of the DES or a benefit with regard to myocardial infarction. Sudden acute thrombosis has become a major concern with DESs.[15–17] The antiproliferative agent of DESs may inhibit the intimal function that induces the anticoagulation process and prohibits

the coagulation process. Even after the agent is completely released, the polymer may remain and cause allergic inflammation, leading to restenosis or thrombotic occlusion. A small but significantly increased risk of death or myocardial infarction was reported recently (0.5%–1.0% per year) in patients who have a DES due to stent thrombosis.[18] Anecdotally, thrombotic occlusion has been reported to occur immediately after cessation of antiplatelet therapy.[19] The U.S. Food and Drug Administration (FDA) stated in December 2006 that use of a DES should be limited to patients who have clinical and coronary anatomical features similar to those of the patients treated in the pivotal trials conducted by the manufacturers for FDA approval. Many cardiologists recommend permanent antiplatelet therapy, including clopidogrel (Plavix; Sanofi Aventis, NJ, USA) or GP IIb/IIIa receptor blocker, after PCI with DES in patients for whom the quality of life or a bleeding event would be worse than with CABG.

Few RCTs of CABG versus PCI with DES have been reported.[20] CABG with bilateral ITA to the left coronary system versus PCI with DES in patients with multivessel disease demonstrated better long-term survival and angina- and intervention-free rates.[21] Because the results of PCI with DESs were not better than those of PCI with BMSs, CABG should be the first option, at least for multivessel disease. PCI can be used to treat proximal lesions, but patients are susceptible to disease progression. As the anastomoses are in the distal portion of the coronary branches with CABG, it could protect against sudden coronary occlusion and myocardial infarction.

CABG without CPB

In 1967, Kolessov grafted the LITA to the LAD through a left thoracotomy under beating-heart conditions.[22] Myocardial revascularization with cardioplegic arrest became the standard CABG procedure with the development of the CPB technique and myocardial preservation methods for cardiac arrest during the early 1980s. The Cleveland Clinic study demonstrated significantly better long-term survival and graft patency with LITA-to-LAD grafting than with saphenous vein grafting, described in 1986 by Loop and associates.[23] LAD proved to be the most important coronary artery, and grafting it with LITA guaranteed 10-year survival and graft patency of more than 90%. Similar results were reported by Kitamura et al. in Japan.[24] On the other hand, the restenosis rate of PCI to a LAD lesion with BMS has been reported to be 20%–30%.

During the late 1990s, a new technique of myocardial revascularization without CPB and with a minimal skin incision was developed by Subramanian[25] and Calafiore et al.[26] A small left thoracotomy in the fourth intercostal space to graft the LITA to the LAD without CPB was called minimally invasive direct coronary artery bypass (MIDCAB), or the left anterior small thoracotomy (LAST) operation. This revival of beating-heart coronary artery surgery was related to the significant cerebral morbidity associated with CPB among high-risk patients. The MIDCAB approach was indicated for patients with single-vessel disease with LAD lesions or those with multivessel disease who had severe co-morbidity, which is not suitable for CPB use. MIDCAB was introduced to Japan during the late 1990s, but its use had almost disappeared there before 1999 because the initial clinical results were disappointing. Cardiac surgeons were not accustomed to the left thoracotomy approach for harvesting the LITA or to an anastomosis under beating-heart conditions (before the introduction of robotic surgical system and a suction-type stabilizer).

The systemic inflammatory reaction initiated by CPB results in an immunological reaction and damage to various organs. Neurological, renal, and gastrointestinal function was impaired by microemboli due to mechanical damage to the blood and aortic wall.

The pioneering efforts by Benetti et al.[27] and Buffolo et al.[28] in South America proved the feasibility of OPCAB through a median sternotomy during the 1990s. Initially, OPCAB was applied to the LAD, diagonal, and main right coronary arteries with minimal hemodynamic alterations during a full median sternotomy. A suction-type mechanical stabilizer and deep pericardial stitches invented by Lima, in addition to an apical suction device, allowed exposure of all coronary branches.[27,30] Trendelenburg positioning by the operating table and other techniques resulted in exposure of the lateral and inferior coronary artery branches.

According to the database of the Japanese Association for Thoracic Surgery, the percentage of OPCAB operations among the total CABG cases was 35% in 2001, 46% in 2002, 55% in 2003, and 60% in 2004. The frequency of OPCAB reached a plateau in 2005 and 2006 according to the database of the Japanese Association of Coronary Artery Surgery. Thus, OPCAB has become the standard method for CABG in Japan, whereas the incidence of OPCAB cases among all CABGs in North America was only 20% and in Germany 5%. As some groups in the United States are performing 90% or more of the CABGs without CPB, the incidence of OPCAB in standard hospitals might be less than 10%.

The indications for OPCAB are the high-risk factors of CPB: cerebrovascular disease, chronic renal failure,

chronic obstructive pulmonary disease (COPD), atheromatous or calcified ascending aorta, old age, and cancer. In contrast, the indications for conventional CABG are unstable hemodynamic status, shock, lethal arrhythmia, percutaneous cardiopulmonary support (PCPS), and discontinuation of OPCAB. Anatomical and physiological contraindications are thought to be intramuscular, diffusely calcified, or extremely small LAD, enlarged left ventricle with poor contractility [LVEF 30%, LV end-diastolic volume index (LVEDVI) >100 ml/m^2], significant mitral regurgitation, and acute myocardial infarction with ventricular tachyarrhythmia. Many retrospective studies have been published comparing clinical outcomes after OPCAB with conventional CABG.[31–33] In moderate-risk and high-risk patients, the operating time, intubation time, length of intensive care unit (ICU) stay, length of hospital stay, perioperative myocardial infarction, amount of bleeding and transfusion, inflammatory reaction, stroke, neurocognitive dysfunction, atrial fibrillation, and inotrope requirements were in favor of OPCAB. For OPCAB, the number of cases of bypass grafting was reported be less than that of standard CABG because of technical difficulty.[34] Graft patency and long-term outcomes in OPCAB cases compared with conventional CABG are still controversial. The meta-analysis of previous RCTs by Cheng and associates[35] showed no significant differences in the 30-day mortality, myocardial infarction, stroke, renal dysfunction, intra-aortic balloon pump (IABP) support, wound infection, rethoracotomy for bleeding, or reintervention for mixed-risk patient population. However, OPCAB significantly decreased atrial fibrillation [odds ratio (OR) 0.58, transfusion (OR 0.43), inotrope requirements (OR 0.48), respiratory infection (OR 0.41), ventilation time (–2.4 h), ICU stay (–0.3 day), and hospital stay (–1.0 day]. Results of graft patency and neurocognitive function were inconclusive. In-hospital and 1-year medical costs were generally higher for standard CABG.

A meta-analysis of 42 nonrandomized trials of high-risk patients by Puskas and associates[36] demonstrated a significant reduction in mortality after OPCAB versus conventional CABG in various high-risk patient subsets (OR 0.58). Mortality was reduced in patient subgroups with high-risk factors of Euroscore >5 (OR 0.39), LV dysfunction (OR 0.55), atheromatous aorta (OR 0.54), and multiple risk factors (OR 0.60). In contrast, increased age, left main coronary artery disease, diabetes mellitus, renal dysfunction, and COPD were not related to the operative mortality irrespective of CPB.

A recent meta-analysis of graft patency by Takagi et al. demonstrated a 27% increase in overall graft occlusion with OPCAB, especially a 28% increase in venous graft occlusion.[37] This result may be related to the hypercoagulability status after OPCAB. Previous reports showed improved venous graft patency with early administration of antiplatelet drugs and no change in LITA grafts irrespective of anticoagulation or an antiplatelet regimen.[38]

Arterial grafts in CABG

The superiority of the ITA graft over a saphenous vein graft (SVG) has been widely accepted since angiographic studies during the 1980s.[23] The clinical importance of LITA-to-LAD grafts was emphasized by a long-term follow-up study compared with SVGs over 20 years.[39] SVGs developed intimal hyperplasia and graft atherosclerosis, which caused late graft occlusion, so various arterial grafts have been adopted over the last 30 years. The right ITA,[40–42] right gastroepiploic artery (GEA),[43,44] radial artery (RA),[45,46] and inferior epigastric artery[47,48] have been used in addition to LITA as in situ grafts, free grafts, or composite grafts. Total arterial OPCAB might be the ideal CABG. According to the database of the Japanese Society of Coronary Surgery in 2004, LITA grafts comprised 38% of all grafts; other arterial grafts were GEA grafts (9%), RA grafts (15%), and SVGs (24%). Thus, arterial grafts account for 76% of all grafts in Japan nowadays, which is significantly higher than in Western countries. Arterial CABGs were performed in 52% of cases according to the database of the Japanese Association for Thoracic Surgery in 2005. Among the OPCAB cases, 66% of CABGs were performed with only arterial grafts in Japan. Although there is no statistical study, it is possible that among the OPCAB cases more than 80% of the grafts were arterial. We believe that total arterial OPCAB should be considered one of the ideal CABGs.[49,50]

There is strong evidence that LITA should be used for revascularization of the LAD artery.[23,24,51–56] Even in patients >80 years of age and in emergent situations, LITA was recommended for LAD revascularization to achieve a better outcome.[57] Crossover RITA-to-LAD was reported to be as good as LITA-to-LAD, although the graft patency of RITA-to-RCA territory was poor.[58,59] There are several comparative studies that showed improved outcomes for patients who had bilateral ITA grafts regarding long-term survival and the cardiac event rate.[60–62] Not a few studies have shown an increase in the risk of deep wound infection by bilateral ITA harvesting, especially in diabetic patients.[63,64] The technique of skeletonizing ITAs with an ultrasonic scalpel may decrease the number of sternal wound complications in diabetic patients.[65,66] Based on our personal experience, bilateral ITA use should be avoided in patients over 80 years of

age, those with insulin-dependent diabetes (IDDM), and those with COPD on medication. Crossover bypass of RITA to LAD should be also avoided when aortic valve stenosis or an aortic aneurysm is present because of a possible future median resternotomy.

The ITA grafts are viable with active biological potency, which has active dilatation and thinning (string phenomenon) of no flow patency.[67] Despite the potential biological superiority of ITA to SVG, which can release nitric oxide from the endothelium to protect against atherosclerosis,[68] flow competition was high when a composite arterial graft was attached to the side of LITA if LAD stenosis was moderate.[69–71] Therefore, we usually use LITA as an individual graft to the LAD when the LAD has only 75% stenosis. As elderly Japanese women have small, fragile ITAs, it might be better to avoid a sequential bypass with ITA and attachment of free graft to ITA.

The RA grafts were revived during the late 1980s when they were found still to be patent in patients who had undergone CABG 13–18 years earlier.[45] The graft, however, is prone to spasm by manipulation because of its thick muscular wall. The technique of harvesting RAs and the use of calcium channel blockers improved early and late graft patency. Acar and associates reported that the 5-year graft patency rate for RA was 84% and that of LITA was 90%.[45] Recently, SVGs have been replaced by RA grafts. Many studies have shown better outcomes with RA grafts than with SVGs,[72–74] although some reported similar long-term graft patency.[75–77] RA grafts frequently showed a flow competitive phenomenon with mildly stenotic native coronary arteries when they were used as composite grafts compared with aorta-to-coronary conduits.[69–71,78] The long-term patency of these competitive RA grafts was poor according to our angiographic analysis.[71] The long-term patency of RA grafts should be better than that of SVGs when good forward flow is present. However, the SVG still has a role as a graft to moderately stenotic RCA territory because of the poor early graft patency of RITA-to-RCA grafts and high incidence of flow competition of composite RA grafts to RCA branches.[58,59,69,70,78]

Use of in situ GEA for CABGs was first reported in 1987, with early graft patency ranging from 90% to 100%.[43,44] The long-term graft patency at 10 years was not better than that for SVGs.[79] GEA is prone to flow competition compared with LITA because GEA is the third branch of the abdominal aorta and has 10–15 mmHg lower pressure at the end compared to the end of LITA.[80–82] Although skeletonized and composite use of GEA has been reported for larger internal diameters and flow, the effect of avoiding flow competition has not been proved.[83–85]

Innovative techniques

Totally endoscopic CABG (TECAB) has been tried in several institutions using a robotic surgical system (da Vinci system; Intuitive Surgical, Sunnyvale, CA, USA).[86,87] The major obstacle to TECAB is the technical difficulty of constructing accurate distal anastomoses. Efforts to put together a distal sutureless automatic anastomosis device are underway. Several automatic anastomosis devices for anastomosis of an SVG to the ascending aorta have been invented. However, most devices were not put on the market because of poor intermediate graft patency and cumbersome handling.[88]

Hybrid therapy for coronary revascularization has been designed. Single-vessel mini-thoracotomy (MIDCAB), followed by angiographic confirmation of the LITA-to-LAD graft and PCI for circumflex and RCA branches has been performed in the hybrid operating room in some centers.[89] Multivessel mini-thoracotomy, which is a LITA-to-LAD bypass combined with a composite RA-to-marginal branch graft, followed by associated PCI with DES in the catheterization laboratory has been tried in a few institutions.

Awake OPCAB has been tried in Turkey in patients who had contraindications to general anesthesia.[90,91] In Japan, awake OPCAB under thoracic epidural anesthesia was attempted by Kanazawa University. These techniques must await further evaluation.

Conclusion

Percutaneous coronary intervention with a drug-eluting stent has dramatically changed the treatment of multivessel coronary artery disease. Appropriate patient education and improvement of surgical techniques with less invasiveness is mandatory for better clinical management of ischemic heart disease. In addition, cardiac surgeons must present these innovations to the public in Japan. CABG is still the best treatment for multivessel disease and left main coronary artery disease.

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虚血性心疾患における冠動脈画像診断の進歩；外科の立場から

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これまで心臓血管外科領域での冠動脈画像診断は，術前の冠動脈造影および冠動脈バイパス術(CABG)術後のグラフト造影が主たるものであったが，multidetector computed tomography(MD-CT)の進歩は，心臓血管外科にも重要な情報を与えてくれるようになってきた．

MD-CTは，心臓外科手術術前には，1)男性40歳以下，女性50歳以下で冠動脈病変のリスク因子がない場合の弁膜症患者の冠動脈スクリーニング，2)超高齢者や脳梗塞の既往があり，心臓カテーテル検査による冠動脈造影(CAG)が危険な弁膜症患者や大動脈弁位の感染性心内膜炎患者での冠動脈評価に有用である．また，MD-CTはCABGの術前診断にも非常に有用である．例えば大動脈頸部分枝および内胸動脈の評価も可能である．さらに，左小肋間開胸心拍動下に左内胸動脈を前下行枝に吻合する低侵襲冠動脈バイパス術(minimally invasive direct coronary artery bypass; MIDCAB)における左内胸動脈と左前下行枝との位置関係(図1)や，心臓カテーテル検査でのCAGで描出されない前下行枝の評価には，より有効である．完全閉塞した冠動脈の分枝の間に狭窄があるかないかを評価することは，不必要なバイパス箇所を減らすために重要であるが，CAGでは評価が困難である．このような場合にもMD-CTでは三次元的に評価が下せる．

MD-CTは，心臓手術術後にも，1)負荷心筋シンチと併用して，CABG術後のグラフトの評価，2)大動脈基部手術術後の冠動脈孔吻合部や吻合部仮性瘤の評価，3)左冠動脈肺動脈起始症における肺動脈内トンネルの評価等にも有用である．

MD-CTによる評価の問題点として，1.0 mm以下の細い冠動脈枝やグラフトは評価困難

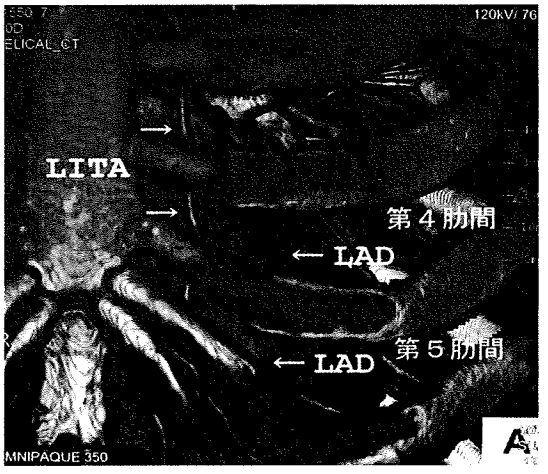

図1　MD-CTによるMIDCAB術前のLITAとLADの位置関係の評価
LITAとLADの近接性から第5肋間よりも，第4肋間での開胸によるMIDCABが望ましいことがわかる．
MIDCAB：minimally invasive direct coronary artery bypass，LITA：左内胸動脈，LAD：左前下行枝

であり，石灰化病変等によるアーチファクトは，従来の心臓カテーテル検査によるCAGに劣ることがあげられる．また，静止画であるため，血流の方向を判定できないので，血流競合を評価しづらい．これらの欠点を考慮しても，低侵襲性はCAGを大きくしのぐものであり，CAGとMD-CTを比較的近い時期に行うことで，両者の欠点を補えるものと考えている．

本特集では，外科の立場から，CABG術後のバイパス評価について報告したい．CABG術後のグラフト開存の確認は必須であるが，侵襲の少ない人工心肺を使用しないCABG(off-pump coronary artery bypass grafting; OPCAB)では低侵襲性が重要といえる．CABG術後の長期予後を良好にするために，動脈グラフトを多用，あるいは動脈グラフトのみを使用するCABGが増加している．これまで，術後のグラフト評価はCAGにて行われてきたが，侵襲的であり，心筋梗塞，脳梗塞，グラフトの解離などの合併症が知られている．われわれは，術後早期のみならず，遠隔期においても外来にて施行できるMD-CTによるCABG術後グラフトことに静脈グラフトよりも細い動脈グラフトの評価を多数起こってきたので，その成績について報告する．

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Predictive factors for the intermediate-term patency of arterial grafts in aorta no-touch off-pump coronary revascularization

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Abstract

Objective: Graft flow is one of the important determinants of the arterial graft patency. To establish the optimal graft design, we examined detailed characteristics of the arterial composite and sequential grafts, and sought to delineate the risk factors of graft occlusion due to insufficient bypass flow. **Methods:** Angiograms of 2547 bypass grafts in 677 consecutive patients who underwent total arterial off-pump CABG without aortic manipulation followed by early postoperative angiography since December 2000 were reviewed. The angiographic flow was graded as A (antegrade), B (competitive), C (reversal), and O (occlusion). **Results:** The overall early graft patency rate was 98.2% (2502/2547). The rate of grade A was 91.3% (2325/2547), while the rates of grades B and C were 2.9% (73/2547) and 4.1% (104/2547), respectively. For the main trunk of the anterior descending branch (LAD), the graft patency rate was 99.3% (674/679). The grade A rate of the internal thoracic artery (ITA) grafts to LAD in an individual fashion was 99.5% (203/204), being comparable with that in the sequential or composite grafting which had two distal anastomoses (98.1%, 159/162; $p = 0.33$). The actuarial patency rates at 3 years were 84.7% for the bypass grafts with grade A flow and 33.9% for those with grade B/C flow, respectively ($p < 0.0001$). The multivariate Cox-regression analysis demonstrated that grade B/C ($p < 0.0001$, HR = 4.19) and 51–75% stenosis of the native coronary artery ($p = 0.02$, HR = 2.86) were significant predictors of graft occlusion. **Conclusions:** For the LAD, the results of graft flow in sequential ITA grafting or composite grafting with two distal anastomoses were comparable with that in individual ITA grafting. Prediction and prevention of competitive and reverse flow are mandatory for achieving the advantages of the arterial materials.

Keywords: Coronary disease; Surgery; Angiography; Off-pump CABG; Arterial graft

1. Introduction

The arterial grafts have beneficial characteristics in terms of expectancy of long-term patency and improved late outcome after coronary artery bypass grafting (CABG) [1–3]. For the arterial grafts, the circumstance of the blood flow in the graft lumen is considered an important determinant of the patency. It has been reported that occlusion or string sign in the arterial grafts can typically occur when the stenosis in the native coronary artery is moderate, and that these physiologic changes in the luminal diameter occurred within 2 years [4–7]. We previously reported that reverse flow in the sequential or composite graft was commonly associated with the moderately stenotic right coronary artery (RCA) and composite or sequential grafting to more than four target branches [8]. In addition, the management of a coronary branch with critical stenosis played definitive roles [9].

The objectives of this study were (1) to delineate the effects of detailed characteristics of the target coronary branches and the bypass grafts on the occurrence of competitive flow, (2) to delineate the risk of graft occlusion, and (3) to establish a theoretical basis for optimizing the strategy for graft arrangement to the left anterior descending artery (LAD) and to non-LAD branches, which include the diagonal branch, left circumflex artery (LCX), and RCA.

2. Methods

The pre- and postoperative coronary angiograms of 2547 bypass grafts in 677 consecutive patients, who underwent off-pump complete revascularization for coronary artery disease using only the internal thoracic artery (ITA) with or without the radial artery between December 2000 and May

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Table 1
Baseline characteristics

No. of patients	677
Age (years)	66.1 ± 9.1
Male/female	563/114
Hypertension	357 (52.7%)
Hyperlipidemia	332 (49.0%)
Diabetes	260 (38.4%)
Left ventricular end-diastolic volume index (ml/m^2)	84.9 ± 29.0
Left ventricular ejection fraction (%)	48.1 ± 11.7
Total distal anastomoses	2547
Distal anastomoses per patient	3.76 ± 1.01
Bypass conduits used	1023
In-situ ITA	293
Composite Y-graft	391
Composite I-graft	273
Composite K-graft	66

ITA, internal thoracic artery.

2006, were reviewed. The patients who had a bypass of the gastroepiploic artery, the inferior epigastric artery or the saphenous vein, those with individual grafts only, and those who did not undergo early postoperative coronary angiography were excluded. All patients provided written informed consent after explanation of the potential risks. All procedures were performed under social insurance coverage, and institutional approval was obtained. There were 563 men and 114 women, and their mean age was 66.1 ± 9.1 years. The number of distal anastomoses was 3.76 ± 1.01 per patient (Table 1).

Early postoperative coronary angiography was performed within a month after surgery. Cardiologists independently evaluated the native coronary artery stenosis and the graft patency. The maximal severity of stenosis was recorded for all target branches. The definitions of terms used in the present study are as follows. A patent graft meant that the graft had a complete continuity of the graft lumen throughout its entire length from the origin of the ITA to the target coronary branch, irrespective of the flow direction. Whenever the continuity of the graft lumen from an in-situ ITA graft to the anastomosis with the target coronary branch was interrupted at any level, or when repeated angioplasty was performed, they were defined as Grade O (occlusion). Grade A was defined as a situation in which antegrade graft flow was found in most of the multi-plane ITA angiographs. Grade B (competitive) was defined as a situation in which the target vessel was slightly opacified from the ITA graft injection, and the bypass graft did fill by retrograde flow from the native coronary injection. Grade C (reverse flow) was defined as a situation in which the distal anastomotic site was not opacified from the ITA graft injection at all, but it did fill clearly by retrograde flow from the native coronary injection. Flow grade was recorded for each target coronary branch, and these data were collected prospectively.

An individual bypass is defined as a bypass conduit having one in-situ ITA and one distal anastomosis. A non-individual bypass graft means a bypass conduit having two or more distal anastomoses, such as sequential or composite grafting. The in-situ ITA is ITA divided only at its distal portion.

2.1. Graft design strategy

The arrangement of the bypass conduits was primarily determined by the operative risk and positional relationship of the target sites. Our current standard technique since March 2003 was based on our previous angiographic studies and introduced for minimizing competitive and reverse flow. One in-situ ITA, usually the left, supplies the LAD territory, while an I-graft of the contralateral ITA, usually the right, and the radial artery supply the LCX and RCA territories in a clockwise orientation, via a side-to-side anastomosis with LCX and an end-to-side anastomosis with RCA. The counterclockwise orientation was occasionally chosen to avoid grafting to RCA branch with 75% stenosis at the end of the conduit, because reverse flow was commonly found at the distal end of the conduit with the end-to-side anastomosis [8,9]. Before introduction of this strategy, the I-graft was used only in a counterclockwise orientation for the safety of redo operation in the future. For patients aged more than 75 years or with considerable operative risks, such as chronic obstructive pulmonary disease or diabetes mellitus treated by insulin therapy, we harvested only a single ITA. In the present series, all ITA grafts were greater than 1.5 mm in diameter at the distal end.

2.2. Late angiographic results

Follow-up angiography was performed between 3 and 66 months after the operation for 325 bypass grafts in 91 patients with recurrent angina, or ischemic findings on electrocardiography or scintigraphy. The mean follow-up period was 29 ± 19 months.

2.3. Statistical analysis

The continuous variables are expressed as the mean values ± standard deviation (SD). The data of two independent groups were compared by Fisher's exact probability test. Longitudinal data were estimated by the Kaplan–Meier method and the difference of two groups was compared by log-rank method. Cox regression analysis was used to examine the significance of the variables in predicting graft occlusion. Statistical analyses were performed using SPSS software (SPSS 8.0 Inc., Chicago, IL). The differences in the outcomes were considered statistically significant when the p-value was less than 0.05.

3. Results

The overall graft patency rate was 98.2% (2502/2547), and the grade A rate was 91.3% (2325/2547). The actuarial graft patency rates at 3 years were 84.7% for the bypass grafts graded A and 33.9% for the bypass grafts graded B/C ($p < 0.0001$). The early patency rate of the bypass grafts to 51–75% stenotic coronary branches was 98.1% (1140/1162), and their grade A rate was 85.1% (989/1162), being significantly lower than that of the bypass grafts to 76–100% stenotic branches (96.5%, 1336/1385; $p < 0.0001$). For 75% stenotic branches, the actuarial graft patency rates at 3

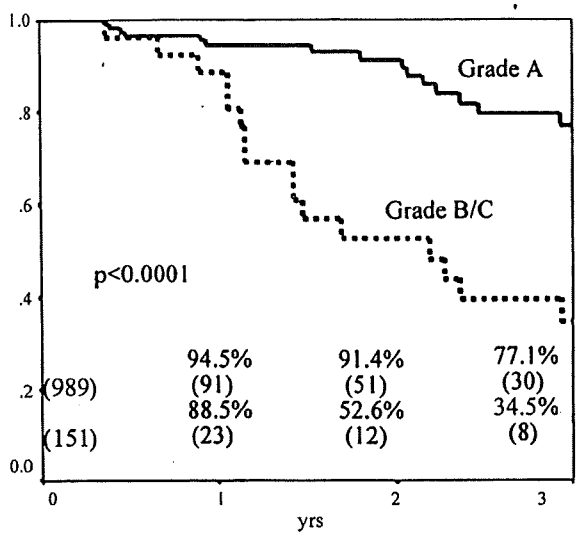

Fig. 1. The actuarial graft patency rate of the bypass grafts to 51–75% stenotic branches. Grade A vs grade B/C.

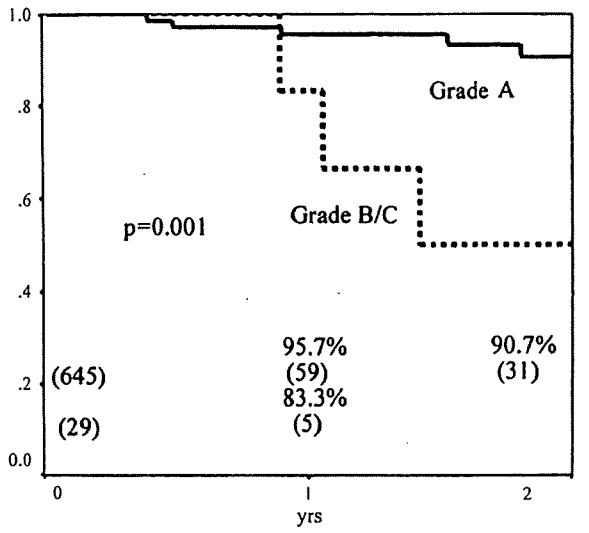

Fig. 2. The actuarial graft patency rate of the bypass grafts to the main trunk of LAD. Grade A vs grade B/C.

years were 77.1% for the bypass grafts graded A and 34.5% for the bypass grafts graded B/C ($p < 0.0001$) (Fig. 1).

Regarding the main trunk of LAD, the grade A rate of the in-situ ITA in individual fashion was 99.5% (203/204), and was significantly higher than that of non-individual conduit grafting (93.1%, 442/475; $p = 0.0001$), whereas the patency rates were similar ($p = 0.99$). The grade A rate of the conduit with two distal anastomoses was comparable with that of the individual grafting ($p = 0.33$) (Table 2). For the bypass grafts to LAD, the actuarial graft patency rates at 1 year were 95.7% for the bypass grafts graded A and 83.3% for the bypass grafts graded B/C ($p = 0.001$) (Fig. 2). The actuarial graft patency rates of the bypass graft to the LAD with 51–75% stenosis and those with 76–100% stenosis at 2 years were 79.9% and 96.7%, respectively ($p = 0.16$).

For the non-LAD branches, including the diagonal, LCX, and RCA branches, the grade A rate of the in-situ ITA was comparable to that of the Y- or K-graft or I-graft (90.8% vs 89.9%; $p = 0.87$), and the grade A rate of the individual grafts was comparable to that of the sequential and composite grafts (91.9% vs 89.9%; $p = 0.99$) (Table 3). The patency rate of the bypass grafts to 51–75% stenotic branches was similar

Table 2
Early angiographic results: flow grading of bypass grafts to main trunk of left anterior descending artery

		No. of anastomoses	Grade A	Grade A rate (%)	Grade B	%	Grade C	%	Grade O	Patency rate (%)
Native coronary stenosis	51–75%	313	288	92.0 [1]	16	5.1	6	1.9	3	99.0 [3]
	76–90%	205	196	95.6 [2]	2	1.0	5	2.4	2	99.0 [4]
	91–100%	161	161	100 [2]	0	0	0	0	0	100 [4]
Diameter of target branch	<1.5 mm	72	68	94.4 [5]	2	2.8	1	1.4	1	98.6
	≥1.5 mm	546	523	95.8 [6]	10	1.8	10	1.8	3	99.5
	Not recorded	61	54	88.5	6	9.8	0	0	1	98.4
Graft material anastomosed	ITA	679	645	95.0	18	2.7	11	1.6	5	99.3
	RA	0	0	–	0	–	0	–	0	–
	Free ITA	0	0	–	0	–	0	–	0	–
Anastomotic fashion	End-to-side (graft end)	675	642	95.1	17	2.5	11	1.6	5	99.3
	Side-to-side (sequential)	4	3	75.0	1	25.0	0	0	0	100
Conduit type	In-situ ITA	275	272	98.9 [7]	1	0.4	0	0	2	99.3
	Y-graft	343	318	92.7 [8]	17	5.0	5	1.5	3	99.1
	K-graft	61	55	90.2 [8]	0	0	6	9.8	0	100
	I-graft	0	0	–	0	–	0	–	0	–
No. of distal anastomoses of conduit	1 (individual)	204	203	99.5 [9,13]	0	0	0	0	1	99.5 [11]
	2	162	159	98.1 [10,14]	2	1.2	0	0	1	99.4 [12]
	3	204	188	92.2 [10]	12	5.9	2	1.0	2	99.0 [12]
	4~	109	95	87.2 [10]	4	3.7	9	8.3	1	99.1 [12]
Total		679	645	95.0	18	2.7	11	1.6	5	99.3

ITA, internal thoracic artery; RA, radial artery. [1] vs [2], $p = 0.001$; [3] vs [4], $p = 0.67$; [5] vs [6], $p = 0.54$; [7] vs [8], $p = 0.0001$; [9] vs [10], $p < 0.0001$; [11] vs [12], $p > 0.99$; [13] vs [14], $p = 0.33$.

Table 3
Early angiographic results: flow grading of bypass grafts to diagonal branch, LCX, and RCA

		No. of anastomoses	Grade A	Grade A rate (%)	Grade B	%	Grade C	%	Grade O	Patency rate (%)
Target branch	Diagonal	391	368	94.1 [1]	9	2.3	7	1.8	7	98.2 [4]
	Circumflex	804	738	91.8 [2]	19	2.4	36	4.5	11	98.6 [5]
	Right coronary	673	574	85.3 [3]	27	4.0	50	7.4	22	96.7 [6]
Native coronary stenosis	51–75%	849	701	82.6 [7]	48	5.7	81	9.5	19	97.8 [9]
	76–90%	500	469	93.8 [8]	7	1.4	12	2.4	12	97.6 [10]
	91–100%	519	510	98.3 [8]	0	0	0	0	9	98.3 [10]
Diameter of target branch	<1.5 mm	614	553	90.1	15	2.4	27	4.4	19	96.9
	>1.5 mm	1121	1015	90.5	34	3.0	57	5.1	15	98.7
	Not recorded	133	112	84.2	6	4.5	9	6.8	6	95.5
Graft material anastomosed	ITA	166	147	88.6 [11]	4	2.4	7	4.2	8	95.2
	RA	1654	1488	90.0 [12]	51	3.1	83	5.0	32	98.1
	Free ITA	48	45	93.8	0	0	3	6.3	0	100
Anastomotic fashion	End-to-side (graft end)	869	709	81.6 [17]	48	5.5	80	9.2	32	96.3
	Side-to-side (sequential proximal)	999	971	97.2 [18]	7	0.7	13	1.3	8	99.2
Conduit type	In-situ ITA	109	99	90.8 [13]	1	0.9	1	0.9	8	92.7
	Y-graft	842	749	89.0 [14]	25	3.0	50	5.9	18	97.9
	K-graft	185	161	87.0 [14]	10	5.4	13	7.0	1	99.5
	I-graft	732	671	91.7 [14]	19	2.6	29	4.0	13	98.2
No. of distal anastomoses of conduit	1 (individual)	37	34	91.9 [15]	0	0	0	0	3	91.9
	2	360	319	88.6 [16]	15	4.2	12	3.3	14	96.1
	3	780	701	89.9 [16]	26	3.3	40	5.1	13	98.3
	4~	691	626	90.6 [16]	14	2.0	41	5.9	10	98.6
Total		1868	1680	89.9	55	2.9	93	5.0	40	97.9

ITA, internal thoracic artery; LCX, left circumflex artery; RA, radial artery; RCA, right coronary artery. [1] vs [3], $p < 0.0001$; [2] vs [3], $p < 0.0001$; [4] vs [6], $p = 0.18$; [5] vs [6], $p = 0.02$; [7] vs [8], $p < 0.0001$; [9] vs [10], $p = 0.87$; [11] vs [12], $p = 0.59$; [13] vs [14], $p = 0.87$; [15] vs [16], $p > 0.99$; [17] vs [18], $p < 0.0001$.

to that of the bypass grafts to 76–100% stenotic branches (97.8% vs 97.9%; $p = 0.87$), while the grade A rate of the bypass grafts to 51–75% stenotic branches was significantly lower than that of the bypass grafts to 76–100% stenotic branches (82.6% vs 96.1%; $p < 0.0001$). The actuarial graft patency rates at 2 years were 94.5% for the bypass grafts graded A and 57.6% for the bypass grafts graded B/C ($p < 0.0001$). The actuarial graft patency rate of the bypass grafts to branches with 76–100% stenosis at 2 years was 89.8%, being significantly higher than that of the bypass grafts to branches with 51–75% stenosis (82.2%; $p = 0.009$). The actuarial graft patency rate of the bypass grafts in the end-to-side fashion at 2 years was 80.5%, being significantly lower than that of the bypass grafts in the side-to-side fashion (91.4%; $p = 0.01$) (Fig. 3A). The actuarial graft patency rates at 2 years were 85.6% for the I-grafts graded A and 88.8% for the bypass grafts graded B/C ($p = 0.31$) (Fig. 3B).

As shown in Table 4, the univariate Cox regression analysis demonstrated that the RCA territory, 51–75% stenosis, small coronary branch (diameter < 1.5 mm), and grade B/C were significant predictors of graft occlusion. The multivariate Cox regression analysis identified 51–75% stenosis (HR = 2.86, $p = 0.02$) and grade B/C (HR = 4.19, $p < 0.0001$) as significant predictors.

4. Discussion

A composite graft allowed total arterial revascularization with excellent graft patency rate and lower incidence of perioperative cardiac and cerebrovascular events [10,11]. Although various arrangements of the in-situ and free arterial grafts have already been reported [3,12,13], no optimal strategy for graft arrangement has been established yet. We have applied our grading system of angiographic graft flow for 5.5 years. The results of the present study imply some suggestions regarding the strategy for graft arrangement.

For the main trunk of the LAD, the use of the in-situ ITA graft has been generally accepted as a standard strategy, which provides a long-term patency and improves the late survival after CABG. The in-situ ITA in an individual fashion may be ideal for the main trunk of the LAD; however, sequential and composite grafting to the LAD and a diagonal branch is an important option of choice. Dion et al. reported that the long-term patency of sequential grafting with the in-situ ITA to the LAD and a diagonal branch was identical to that of the individual in-situ ITA [14]. We previously reported that early angiographic results of the Y-graft to the LAD and a diagonal branch were similar to that of sequential grafting [9]. As shown in Table 2, our present study demonstrated that, in the LAD region, the sequential graft and the Y-graft to two distal anastomoses were as reliable as individual grafting. We consider that the in-situ ITA, which is anastomosed to the LAD, can be connected with at least one diagonal branch by sequential or composite grafting without disturbance of graft flow to the main trunk of the LAD. Different from bypass grafts to LCX or RCA, the difference between the patency rate of bypass grafts to LAD 51–75% and that of bypass grafts to 76–100% stenosis was not significant. The in-situ ITA grafts could confidently supply the

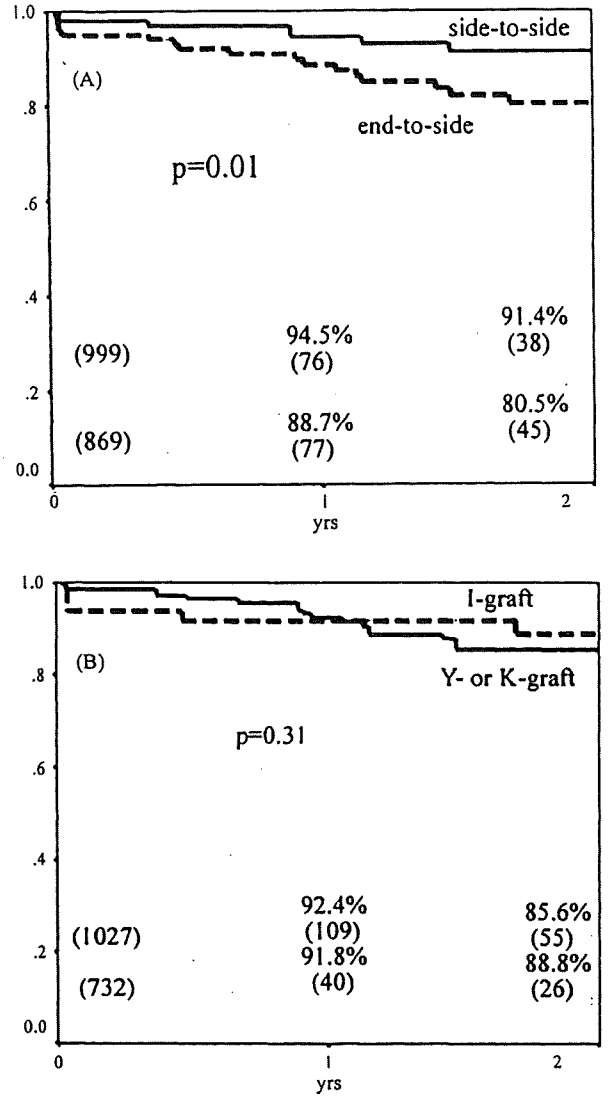

Fig. 3. (A) The actuarial graft patency rate of the bypass grafts to the non-LAD branches. End-to-side anastomoses (graft end) vs side-to-side anastomoses. (B) The actuarial graft patency rate of the bypass grafts to the non-LAD branches. I-graft vs Y- or K-graft.

sufficient antegrade flow to the LAD territory, even with moderate stenosis.

For the coronary branches besides LAD, there was no obvious disadvantage of the composite grafts versus the individual graft and the in-situ ITA. In addition, native coronary stenosis had stronger impact on the bypass grafts to the non-LAD branches than on the bypass grafts to the LAD in the follow-up angiographic results. For the bypass grafts to the non-LAD regions, both grade B/C and 51–75% stenosis in the native coronary branch significantly correlated with graft occlusion.

One of the possible explanations for these differences between the grafts to LAD and those to non-LAD branches may be the difference in the graft materials. About 90% of the anastomoses were performed with the composite radial artery. The radial artery may be more sensitive for the blood flow in the lumen than the ITA graft. More severe stenosis will be necessary for the long-term patency of the radial artery, as compared with the ITA graft.

Regarding the conduit type, no significant difference was found between the I-graft and the Y- or K-graft in the non-LAD regions. We consider that the appropriate pressure slope in each segment of the bypass conduit, highest at the proximal and lowest at the end of the conduit, was the most important for antegrade bypass flow to all target vessels. The bypass grafts with the side-to-side anastomoses presented better graft patency than those with the end-to-side anastomoses. Therefore, when the positional relationship of the target sites allows, the I-graft would be favorable, because it has only one end-to-side anastomosis and the target coronary branch at the end of the conduit can be changed by simply determining its orientation. On the other hand, the Y-graft has the advantages of increased flow capacity [15] and availability to the distant target branches.

Dion et al. reported that the patency rate of end-to-end grafting was comparable with side-to-side grafting with excellent long-term patency of sequential grafting using the ITA graft [14]. In their report, the target branches of 78% of bypass graft restudied were the LAD and a diagonal branch, whereas, in the present study, sequential ITA grafting to the LAD and a diagonal branch was only 9%, and sequential grafting to four or more target branches was performed in about 11% of patients. We consider that the difference is owing to differences in target site, graft material, and probably the number of target coronaries in sequential anastomoses.

Selection of patients suitable for this procedure would be a next concern. It has been widely accepted that the patients with severe atherosclerosis of the ascending aorta are the most suitable candidates for composite and sequential grafting [10,11]. We would suggest herein new patients' selection criteria from a viewpoint of preventing competitive flow and maximizing durability of arterial grafts. According to the results of the present study and our previous investigations, the decisive risks of competitive and reverse flow are as follows: (1) a RCA branch with 51–75% stenosis, (2) a LCX branch with 51–75% stenosis, (3) a bypass conduit with four or more distal anastomoses, and (4) three high-risk situations reported in [9]. Of 677 patients in this study, 147 (21.7%) patients had none of these risks and/or all risky situations were successfully avoided. The actuarial graft patency rate of patients who have none of the above risks at 3 years was significantly higher than that of patients with any of the risks (92.6% vs 69.7%; $p < 0.0001$). They were the best candidates for this procedure. On the other hand, when competitive or reverse flow is highly predicted, alternative strategies, such as the aortocoronary bypass, which provides the highest bypass pressure [16], may be reasonable, especially for the non-LAD regions.

The present study had some limitations. First, the patients who underwent follow-up angiography were biased toward clinically evident graft failure. Second, the peripheral vascular resistance in the myocardial tissue, which has an important role in the coronary perfusion, was not taken into account. Third, the capacity of the ITA graft was not considered. The pressure and flow capacity as the blood source of the bypass conduit and potentiality of growth or thinning and adaptability to the graft flow may also play important roles in the occurrence of insufficient flow and resultant occlusion. At the beginning of 2004, we started to harvest ITA in a skeletonized fashion to maximize the

Table 4
Predictors of graft occlusion in the intermediate-term follow-up period

Variables	Hazard ratio	95% CI	p-Value
Univariate analysis			
Female	1.17	(0.55–2.47)	0.68
Distal anastomoses of the conduit	1.00	(0.78–1.29)	0.99
Early period (Dec. 2000–Feb. 2003)	0.91	(0.50–1.66)	0.76
Type of the conduit, Y- or K-graft (vs in-situ ITA)	0.66	(0.31–1.42)	0.29
Type of the conduit, I-graft (vs in-situ ITA)	1.02	(0.45–2.32)	0.96
Graft material anastomosed, radial artery (vs in-situ ITA)	1.39	(0.81–2.38)	0.23
Graft material anastomosed, free ITA (vs in-situ ITA)	2.51	(0.74–8.55)	0.14
Location, LCX territory (vs LAD territory)	0.98	(0.51–1.90)	0.95
Location, RCA territory (vs LAD territory)	2.44	(1.41–4.23)	0.001
Stenosis (51–75%)	2.28	(1.35–3.83)	0.002
Diameter of coronary branch (<1.5 mm)	1.94	(1.12–3.36)	0.01
End-to-side anast. (graft end) (vs side-to-side = sequential proximal)	1.48	(0.87–2.53)	0.15
Grade B/C in early angiography	6.46	(3.64–11.47)	<0.0001
Multivariate analysis			
Graft material anastomosed, radial artery (vs in-situ ITA)	0.51	(0.10–2.70)	0.43
Graft material anastomosed, free ITA (vs in-situ ITA)	1.24	(0.14–11.35)	0.84
Location, LCX territory (vs LAD territory)	1.88	(0.37–9.57)	0.45
Location, RCA territory (vs LAD territory)	3.27	(0.65–16.35)	0.15
Stenosis (51–75%)	2.86	(1.17–6.99)	0.02
Diameter of coronary branch (<1.5 mm)	1.57	(0.78–3.14)	0.20
End-to-side anast. (graft end) (vs side-to-side = sequential proximal)	1.12	(0.53–2.33)	0.77
Grade B/C in early angiography	4.19	(2.02–8.69)	<0.0001

CI, confidence interval; LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; ITA, internal thoracic artery; RA, radial artery.

capacity of the in-situ ITA graft [17,18]. This technique will extend the application of the bilateral ITA grafting to patients with a substantial operative risk [19]. Fourth, the effects of the luminal size of arterial conduits on the long-term patency remain unclear. Previously, the grading system of the luminal size at the narrowest portion, and intimal irregularity was reported [20,21]. It was reported useful for assessment of degeneration of bypass grafts in a conventional technique. However, the luminal size of the side-to-side anastomosis in the sequential fashion is not precisely measurable, especially when the angle between the graft and the coronary branch is near 90 degrees, or when the contrast medium only fills incompletely due to mixture with the blood flow from the native coronary artery. Moreover, the regression of stenosis and the increase of the diameter were relatively common findings in the arterial materials [22,23]. At last, high-pressure injection of contrast medium may induce reverse and competitive flow and may interfere with evaluation of graft flow direction. This may be a methodological limitation. This flow grading system is not necessarily practical for postoperative evaluation for each patient and each bypass graft. In the present study, flow grading was performed independently from the catheterization team. We utilized this grading system for comparison of graft configurations and optimizing the strategy for design of the arterial grafts, based on data of a considerable number of patients and bypass grafts, and examined significance of correlations between characteristics of the bypass grafts and the occurrence of competitive and reverse flow. For these purposes, flow grading is considered useful.

In conclusion, prediction and prevention of competitive and reverse flow may be necessary to enhance the advantage of multivessel revascularization using exclusively arterial materials because insufficiency of the antegrade flow would spoil the advantage of arterial grafts.

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ACSに対する冠血行再建術 OPCABの立場から

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はじめに

日本人の冠動脈疾患は年々増加し，虚血性心疾患に対する本邦の手術件数は，胸部外科学会統計によれば2000年には2万例を超えた[1]．その手術成績も向上し，2004年の初回待機的冠動脈バイパス手術（CABG）の病院死亡率は1.5%にまで低下している[2]．しかしながら，緊急症例に対するCABGの病院死亡率は8.8%と，待機手術と比べて著しく高い．このような緊急手術の適応となる急性冠症候群（ACS）における人工心肺を使用しないCABG（OPCAB）の役割について述べたい．

ACSは，冠動脈の粥腫破綻・血栓形成によりおこる急性心筋虚血を呈する広範な疾患概念であり，急性心筋梗塞（AMI）及び不安定狭心症の一部を含む．不安定狭心症の内ACSに含むべきは梗塞後狭心症と安静時狭心症である．また，AMIはSTEMI（ST-elevation MI）とNSTEMI（non-STEMI）でその治療戦略も異なるので別々に論じる必要がある．今回は安静狭心症とAMIに対するCABGに分けて検討する．

安静時狭心症の外科治療

安静時狭心症は，AMIに移行する可能性の高い疾患群で，緊急の経皮的冠動脈インターベンション（PCI）あるいはCABGを考慮した適切な診断・治療を行う必要がある．従って，症状が安定しない場合には，Braunwaldらのガイドライン[3]にしたがって，1）薬物療法抵抗例，2）以前に冠動脈インターベンション（PCI）あるいはCABGが施行されている症例，3）低左心機能症例，4）臨床的ハイ・リスク症例（20分以上持続する胸痛・肺水腫・僧帽弁閉鎖不全・広範なST-T変化・III音及び湿性ラ音聴取・発作時血圧低下）にはすみやかに冠動脈造影を行う必要がある．

冠動脈造影の結果，1枝病変はPCIの適応と考えられるが，1）左冠動脈主幹部病変，2）3枝病変，3）左前下行枝近位部狭窄を含む2枝病変でことに糖尿病や左室機能が低下している（左室駆出率50%以下）症例，PCIが困難あるいは禁忌と考えられる症例ではCABGを行うべきである[4]．これは，Drug Eluting Stent（DES）全盛のPCI時代においても同様である．しかしながら，近年患者の高齢化や脳血管病変・上行大動脈病変（石灰化やアテローム変性）・腎不全など，他臓器の障害を有する患者が増加してきており，人工心肺を用いたCABGだけでなく，OPCABを考慮に入れた治療戦略をたてる必要がある．

1980年代の報告として，Coronary Artery Surgery Study（CASS）[5]では，不安定狭心症に対するCABGの手術死亡率は3.9%で，7年生存率は79%であった．手術死亡の危険因子は，年齢・左室機能低下・左冠動脈優位の左冠動脈主幹部病変であったが，安定労作狭心症との間で手術死亡率に差がなかった．また遠隔死亡の危険因子は左室機能低下・うっ血性心不全・合併症・重症冠動脈病変・心拡大であった．National Heart, Lung, and Blood Instituteによる National Cooperative Study Group（NCSG）[6]の報告では，手術死亡率は3.7%であった．この数値は慢性労作性狭心症の手術死亡率の約2倍であり，周術期の心筋梗塞発生率9.9%，低心拍出量症候群の発