The Risk Factor Analysis for the Late Graft Failure of Radial Artery Graft in Coronary Artery Bypass Grafting

Mitsuharu Hosono, MD, PhD, Takashi Murakami, MD, PhD, Hidekazu Hirai, MD, PhD, Yasuyuki Sasaki, MD, PhD, Shigefumi Suehiro, MD, PhD, and Toshihiko Shibata, MD, PhD

Introduction

Long-term outcome after coronary artery bypass grafting (CABG) is associated with the patency of the grafts used. Because of its good long-term patency, left internal thoracic artery (LITA) grafting is acknowledged as the gold standard in CABG for revascularization of the left anterior descending coronary artery. In addition to LITA grafts, several types of arterial grafts have been used in CABG.

Among the various arterial grafts, the use of the radial artery graft (RAG) in CABG was reported by Carpentier and colleagues. Initial angiographic studies revealed that the follow-up patency was not favorable. However, RAGs have been included in arterial graft since the revival of its use was reported by Acar et al. Since then, RAG patency rates have been reported to range from 74% to 98% at ≥5 years after CABG. Although early results of radial artery grafting are encouraging, issues remain with regard to long-term results. Furthermore, there remains a

Objective: The aim of this retrospective study was to investigate the early operative results and detect the factors influencing the fate of radial artery grafts (RAGs) by evaluating the mid-term patency.

Methods: We retrospectively reviewed 410 patients who underwent isolated coronary artery bypass graft using RAG. RAGs were anastomosed to 526 coronary arteries. Mid-term angiography was performed in 214 patients at an average 4.9 years after the operation.

Results: The early patency of RAGs was 97.6%. Cumulative 5-year patency was 86.5% for RAG, 94.1% for LITA graft, and 81.0% for saphenous vein graft (SVG). RAG was significantly superior to SVG in mid-term patency. Individual grafting (not sequential grafting) (hazard ratio [HR]: 2.535; 95% confidence interval [CI]: 1.293–5.281; p = 0.006) and grafting to the target coronary artery with ≤75% proximal stenosis (HR: 1.947; 95% CI: 1.090–3.484; p = 0.025) were found to be independent risk factors influencing late RAG patency.

Conclusions: The patency of RAGs was superior to that of SVGs in the studied population. When using RAGs, grafting to the target vessel with severe proximal stenosis is favorable. The RAG is suitable for sequential grafting.

Keywords: radial artery graft, coronary artery bypass grafting, graft patency

Department of Cardiovascular Surgery, Osaka City University Graduate School of Medicine, Osaka, Osaka, Japan

Received: March 1, 2018; Accepted: July 7, 2018

Corresponding author: Mitsuharu Hosono, MD, PhD. Department of Cardiovascular Surgery, Osaka City University Graduate School of Medicine, 1-4-3 Asahimachi, Abeno-Ku, Osaka, Osaka 545-8585, Japan

Email: mi_hosono@hotmail.com

©2019 The Editorial Committee of Annals of Thoracic and Cardiovascular Surgery. This work is licensed under a Creative Commons Attribution-NonCommercial-NonDerivatives International License.
lack of consistent and robust clinical study about long-term patency comparing the RAG and the saphenous vein graft (SVG). From results of previous clinical data, the patency of the RAG may be affected by patient characteristics, anatomical characteristics of the coronary artery, and other factors. Thus, although RAGs are easily harvested and versatile and have excellent handling characteristics, some factors that potentially influence its patency remain a concern. This retrospective study was designed to investigate the early operative results of CABG using RAGs and to detect the factors influencing the fate of the RAG by evaluating its mid-term patency.

Patients and Methods

Patients
We retrospectively reviewed 410 patients who underwent primary CABG using RAGs. Operations were performed from January 1997 to December 2015. The patients’ profiles are summarized in Table 1. In this study, there were 1462 distal anastomoses in total: 418 anastomoses were constructed with LITA grafts, 526 with RAGs, 473 with SVGs, 26 with the right internal thoracic artery, 15 with the right gastroepiploic artery, and 4 with the inferior epigastric artery. The distal anastomotic sites were summarized in Table 2. The mean number of distal anastomoses per patient in CABG was 3.6 ± 1.0. There were 65 (15.9%) emergent or urgent cases. Off-pump CABG was performed in 55 cases (13.4%). The mean operation time was 354.6 ± 80.6 min. In on-pump CABG cases, mean extracorporeal circulation time was 161.6 ± 42.8 min and aortic clamping time was 124.1 ± 32.4 min.

Surgical technique
We have harvested RAGs as a skeletonized graft. The RAG was usually harvested from the non-dominant forearm. Distal anastomosis was conventionally constructed in a parallel configuration on an individual grafting. Side-to-side anastomoses in sequential RAGs were constructed in a diamond shape, and end-to-side anastomoses in sequential RAGs were constructed in a right angle or a parallel configuration depending on the graft and the coronary artery axis. The target vessel and graft arteriotomy length in the diamond configuration were tailored to prevent a “seagull” deformity. Conventionally, proximal anastomoses of RAGs were constructed on the ascending aorta. In patients whose proximal anastomoses of RAGs were constructed on the LITA in a parallel configuration.

Table 1 Patients’ profile

|                         |            |
|-------------------------|------------|
| Male:female             | 336:74     |
| Age (years)             | 64.6 ± 8.6 |
| Obesity                 | 80 (19.5)  |
| Hypertension            | 287 (70.0) |
| Dyslipidemia            | 258 (62.9) |
| Diabetes mellitus       | 217 (52.9) |
| Smoking                 | 245 (59.8) |
| Serum Creatinine >2.0 mg/dL | 8 (2.0) |
| Hemodialysis            | 2 (0.5)    |
| Peripheral arterial disease | 45 (11.0) |
| History of CVA          | 52 (12.7)  |
| PCI history             | 119 (29.0) |
| CCS 3, 4                | 156 (38.0) |
| NYHA III, IV            | 81 (19.8)  |
| LVEF <40%               | 62 (15.1)  |
| Left main trunk disease | 130 (31.7) |
| Three-vessels disease   | 315 (76.8) |
| Two-vessels disease     | 84 (20.5)  |
| One-vessels disease     | 11 (2.7)   |
| Preoperative IABP       | 41 (10.0)  |

Values are expressed as mean ± standard deviation or patient number (percentage). CVA: cerebrovascular accident; PCI: percutaneous coronary intervention; CCS: Canadian cardiovascular society functional class; NYHA: New York heart association functional class; LVEF: left ventricular ejection fraction; IABP: intra-aortic balloon pumping

Graft management
An Allen’s test and preoperative ultrasonographical assessment of the radial artery were routinely performed. After harvesting, 10 mL of papaverine solution (0.2 mg/mL in heparinized arterial blood) was injected intraluminally, and the RAG was stored in the same solutions until ready for grafting.

During intensive care unit stay, continuous drip infusion of diltiazem chloride was used (0.5 μg/kg/min) until the administration of oral drug commenced. Oral diltiazem chloride was used routinely in patients with RAGs unless contraindicated by hypotension or bradycardia. The patients with SVGs received oral warfarin potassium for 6 months.

Angiographic studies
Early postoperative coronary angiography was performed in 356 patients. Follow-up coronary angiography or multi-slice computed tomography angiography was conducted to assess graft patency in 214 patients who gave their informed consent. There were 48 symptomatic patients (22.4%). In all, 117 coronary angiographies
and 211 multi-slice computed tomography scans were included in this study. These studies were performed at a mean 4.9 ± 3.4 years after surgery. Both studies were reviewed and evaluated by interventional cardiologists. A coronary graft was considered to be a failure in cases of high stenosis (>75%) or complete occlusion of the graft and/or an anastomosed coronary artery, or in cases of string sign. In sequential grafting, both anastomotic sites were counted as an occlusion in cases of an occluded proximal side of the graft and patent distal anastomotic sites.

Statistical analysis
All data were obtained by retrospective review of medical records. Statistical analysis was performed with the JMP 11 software package (SAS Institute Inc., Cary, NC, USA). Categorical variables are expressed as direct number and percentage are given where appropriate. Continuous variables are expressed as mean and standard deviation unless otherwise stated. Cumulative patency curves were constructed using the Kaplan–Meier method and compared using the log-rank test. Univariate and multivariate Cox proportional hazards regression analyses were used to detect independent risk factors influencing late RAG patency. The significant factors in univariate analysis (p < 0.05) were forward analyzed with multivariate analysis to identify the independent risk factors. In all analyses, a value of p < 0.05 was considered significant.

| Table 2 | Anastomotic sites |
|---------|-------------------|
|         | LITA  | RAG  | SVG  | Other |
| LAD     | 409   | 93   | 74   | 20    |
| LAD     | 378   | 8    | 1    | 11    |
| D       | 31    | 85   | 73   | 9     |
| LCX     | 9     | 229  | 248  | 5     |
| OM      | 1     | 113  | 88   | 2     |
| PL      | 8     | 116  | 160  | 3     |
| RCA     | 0     | 204  | 151  | 20    |
| #3RCA   | 0     | 29   | 18   | 6     |
| #4PD    | 0     | 143  | 78   | 11    |
| #4AV    | 0     | 32   | 55   | 3     |
| Total   | 418   | 526  | 473  | 45    |

LITA: left internal thoracic artery; RAG: radial artery graft; SVG: saphenous vein graft; LAD: left anterior descending; D: diagonal branch; LCX: left circumflex artery; OM: obtuse marginal artery; PL: posterolateral artery; RCA: right coronary artery; PD: posterior descending artery; AV: atrioventricular node branch

| Table 3 | Early operative results |
|---------|-------------------------|
| Mean ICU stay (days) | 1.9 |
| Low output syndrome | 15 (3.7) |
| Perioperative MI | 6 (1.5) |
| Prolonged ventilation | 28 (6.8) |
| Re-exploration for bleeding | 5 (1.2) |
| Multiple organ failure | 2 (0.5) |
| Cardiac tamponade | 3 (0.7) |
| Hemodialysis | 11 (2.7) |
| Cerebral infarction | 2 (0.5) |
| Deep sternal infection | 7 (1.7) |
| Hospital death | 5 (1.2) |

Values are expressed as patient number (percentage) except for mean ICU stay. ICU: intensive care unit; MI: myocardial infarction

Results

Operative results and early patency
The early operative results are summarized in Table 3. There were five hospital deaths (1.2%), the causes of which were low output syndrome in two cases, uncontrollable ventricular fibrillation in one case, mediastinitis in one case, and cerebral infarction in one case.

In 356 patients (86.8%), postoperative coronary angiography was performed (with informed consent) during postoperative hospitalization. The early patency was 99.2% (365/368 anastomoses) for LITA grafts, 97.6% (448/459 anastomoses) for RAGs, 96.4% (398/413 anastomoses) for SVGs, and 97.1% (34/35 anastomoses) for other arterial grafts.

Follow-up patency
Cumulative 5-year patency rates were 94.1% for LITA grafts, 86.5% for RAGs, and 81.0% for SVGs (Fig. 1). The follow-up patency of the LITA grafts was significantly superior to that of the other two grafts (p < 0.01) while that of RAG was significantly superior to SVG (p = 0.04).

Risk factor for mid-term RAG patency
Upon univariate Cox regression analysis, three factors were detected as a risk for late patency (Table 4): individual grafting (not sequential grafting) (hazard ratio [HR]: 2.999; 95% confidence interval [CI]: 1.595–6.046; p < 0.001), grafting to the target coronary artery with ≤75% proximal stenosis (HR: 1.828; 95% CI: 1.026–3.263; p = 0.041), and grafting to the right coronary artery (HR: 2.278; 95% CI: 1.282–4.075; p = 0.005). Multivariate
Radial Artery Graft Patency in CABG

analysis after univariate analysis identified two significant independent factors influencing late RAG patency: individual grafting (HR: 2.535; 95% CI: 1.293–5.281; \( p = 0.006 \)) and grafting to the target coronary artery with \( \leq 75\% \) proximal stenosis (HR: 1.947; 95% CI: 1.090–3.484; \( p = 0.025 \)).

Discussion

The early operative results of several studies have indicated that the RAG can be used as a useful arterial graft in CABG.\(^2\)\(^,\)\(^8\)\(^,\)\(^9\)\) The present study also demonstrates low operative mortality and good early patency (97.6%). These results suggest that there are no technical difficulties in anastomosis and graft arrangement when using RAG. Although early results of radial artery grafting are encouraging, issues remain with regard to long-term results. Some clinical follow-up data showed good CABG results when using RAG in comparison with SVGs.\(^5\)\(^,\)\(^10\)\) On the other hand, some studies reported lower RAG patency.\(^11\) Therefore, it is difficult to draw a definite conclusion regarding long-term graft patency. When evaluating graft patency many factors should be considered, such as patient’s clinical profile, medication, operative method, and target coronary artery condition and run-off. There remains a lack of well-organized clinical analysis of long-term patency comparing RAGs and SVGs that take into account the numerous factors potentially influencing the long-term patency of the grafts. Meanwhile, knowledge of the factors that may influence the patency of each graft is important.

During this studied period, RAGs were used as a second arterial graft in our institute. We found their midterm patency to be superior to that of SVGs. Multiple arterial coronary artery grafting improves long-term survival compared with single arterial CABG, but the best second arterial conduit to be used with the LITA remains undefined.\(^12\) Another possible alternative as a second graft is the right internal thoracic artery. Bilateral internal thoracic artery has reportedly achieved good outcomes in CABG. We therefore also used the right internal thoracic artery in patients without a high risk of sternal complications during the studied period. However, the right internal thoracic artery was not frequently used during the studied period since a RAG can be used for more distal territory than in situ right internal thoracic artery graft and it is used for sequential multiple grafting. In recent years, the number of patients who underwent CABG using right internal thoracic arteries is increasing in our institute using as a free graft. The free right internal thoracic arteries also can be used for sequential graft, but their superiority to RAG regarding long-term graft patency has not yet been established.\(^5\)\(^,\)\(^13\) According to the society of thoracic surgeons clinical practice guidelines on arterial conduits for CABG, as an adjunct to LITA, a second arterial graft (right internal thoracic artery or RAG) should be considered in appropriate patients.\(^13\) Further systematic comparative studies on the issue are necessary.

The RAG can be used as a free graft and is suitable for use in sequential grafting. Schwann and colleagues\(^14\) mentioned that sequential RAG patency compares favorably with their previously reported single RAG patency in symptomatic patients.\(^15\) Although the sample size was relatively small, Emir and colleagues\(^16\) also proposed sequential radial artery grafting as a method of choice for maximizing arterial graft survival and patency. Improved patency in a sequential versus single SVG configuration has been reported and widely accepted\(^17\) although superiority of sequential RAG in comparing with single RAG in late patency is yet to be established. However, the flow dynamics reported in sequential SVGs may have a similar favorable effect on RAGs since sequential grafting decreases total resistance to graft flow.\(^18\) When performing sequential grafting, the target vessel condition and graft arrangement are crucial factors influencing graft patency. Likewise in sequential radial artery grafting, careful graft arrangement is important in minimizing concerns about coronary steal and graft flow reversal.\(^19\) Severity of stenosis in the most distal target was reported to have a significant impact on prevention of competitive
flow and long-term patency in all targets. The graft arrangement regarding target coronary artery condition, run-off and severity of proximal stenosis may contribute to good patency of sequential RAGs. As indicated above, since sequential RAG patency is thought to be favorable, sequential radial artery grafting can facilitate maximization of the number of arterial graft reconstructions.

In the present study, severity of proximal target vessel stenosis was also found to be a risk factor for late RAG patency. Proximal stenosis of the target vessel of >75% is preferable for late patency. Previous studies suggested that grafting to a target vessel with more severe proximal stenosis improved the graft patency, although the reported threshold of proximal stenosis severity varies. Hata et al. demonstrated that target vessel stenosis <75% was a risk for RAG patency. In some studies, stenosis of ≥90% was defined as severe proximal stenosis while other recommended stenosis of >80% in grafting to the right coronary artery. Regardless of the extent of proximal stenosis, severe stenosis is important for RAG patency. Miwa et al. reported that very high-grade proximal lesions was also associated with a much lower incidence of diffuse narrowing, known as string sign. Adaptive narrowing of the RAG in the setting of flow competition may lead to graft occlusion. It was previously suggested that reduced flow in arterial conduits may lead to low shear stress, inducing graft dysfunction. By contrast, some reports reported a reversal of the arterial graft string sign. While the relation between the string sign and graft occlusion is unclear, the string sign was included in graft occlusion in this study.

Target location may also affect the patency of grafts. Some studies reported that RAGs to targets of the right coronary artery appear to be at high risk of graft failure. However, other factors such as site (proximal or distal), size, and degree of proximal stenosis seem to have more influence on the late patency of RAG when grafted to the right coronary artery. In the present study, grafted to the right coronary artery was detected as a risk factor for graft failure in univariate analysis, while not being an independent risk factor in multivariate analysis. The reason for this result is that sequential grafting was used more frequently for circumflex arterial territory revascularization than for the right coronary territory in our study population. Sequential grafting may more strongly affect late RAG patency than target location.

Our study has several limitations. This study is subject to the limitations inherent to retrospective observational data studies. Although the study cohort is from a single surgical group, graft selection was at the discretion of the surgeon and subject to bias. Renal dysfunction was suggested to impair RAG patency. However, in general, RAG was not used for patients with severe renal dysfunction.

| Table 4 Univariate analysis of the risk factor for radial artery graft patency |
|---------------------------------|-----------------|---------------|---------------|
|                                | Univariate analysis | Multivariate analysis |
|                                | HR | 95% CI | p value | HR | 95% CI | p value |
| Age (/year)                     | 1.016 | 0.982–1.052 | 0.377 | 1.828 | 1.026–3.263 | 0.041 |
| Female gender                   | 0.757 | 0.288–1.655 | 0.511 | 0.994 | 0.977–1.015 | 0.567 |
| Obesity                         | 1.052 | 0.454–2.146 | 0.898 | 0.998 | 0.995–1.002 | 0.329 |
| Hypertension                    | 1.304 | 0.723–2.445 | 0.384 | 1.828 | 1.026–3.263 | 0.041 |
| Hypercholesterolemia            | 0.711 | 0.398–1.306 | 0.265 | 0.994 | 0.977–1.015 | 0.567 |
| Diabetes mellitus               | 0.655 | 0.366–1.168 | 0.150 | 0.994 | 0.977–1.015 | 0.567 |
| Smoking history                 | 1.305 | 0.726–2.422 | 0.379 | 0.994 | 0.977–1.015 | 0.567 |
| Serum creatine level (/mg)      | 1.617 | 0.278–4.231 | 0.830 | 0.994 | 0.977–1.015 | 0.567 |
| Peripheral artery disease       | 1.211 | 0.631–2.519 | 0.578 | 0.994 | 0.977–1.015 | 0.567 |
| History of CVD                  | 2.082 | 0.790–4.566 | 0.127 | 0.994 | 0.977–1.015 | 0.567 |
| NYHA                            | 1.038 | 0.768–1.377 | 0.805 | 0.994 | 0.977–1.015 | 0.567 |
| LV ejection fraction (/%)       | 0.994 | 0.977–1.015 | 0.567 | 0.994 | 0.977–1.015 | 0.567 |
| Operation time (/minute)        | 0.998 | 0.995–1.002 | 0.329 | 0.994 | 0.977–1.015 | 0.567 |
| Coronary stenosis ≤75%          | 2.999 | 1.595–6.046 | <0.001 | 1.828 | 1.026–3.263 | 0.041 |
| Individual grafting             | 2.278 | 1.282–4.075 | 0.005 | 1.828 | 1.026–3.263 | 0.041 |
| Grafted to RCA                  | 2.281 | 0.783–5.305 | 0.120 | 1.828 | 1.026–3.263 | 0.041 |
| Composite                       | 2.281 | 0.783–5.305 | 0.120 | 1.828 | 1.026–3.263 | 0.041 |

HR: hazard ratio; CI: confidence interval; CVD: cerebrovascular disease; NYHA: New York heart association functional class; LV: left ventricular; RCA: right coronary artery
in our institute, to enable a future shunt for hemodialysis. Selection of the target location for the RAG was also at the discretion of the surgeon. Because RAGs are shorter than SVGs, they can be difficult to use for grafting to the distal branch of the circumflex artery in some cases. This fact might affect the result that RAGs were used both in circumflex and right coronary artery almost equally, whereas SVGs were used more for the circumflex territory than right coronary artery in this study (Table 2). Small target vessel size may affect late patency. However, the size of the target vessel was not considered in this study because vessel size was not recorded in all patients. Finally, during follow-up, there were no assessments of patients’ status, such as lipid levels, glycemic control, or smoking or medication compliance.

Conclusion

Early patency and operative results of CABG using RAG are favorable. RAG patency was superior to that of SVGs in this studied population. RAG represents a viable alternative for arterial grafting in CABG. When using RAGs, grafting to the target coronary artery with >75% proximal stenosis is favorable. Furthermore, RAGs are suitable for sequential grafting.

Disclosure Statement

None of authors had a conflict of interest concerning this study, and none received outside support for this research.

References

1) Carpentier A, Guermonprez JL, Deloche A, et al. The aorta-to-coronary radial artery bypass graft. A technique avoiding pathological changes in grafts. Ann Thorac Surg 1973; 16: 111-21.
2) Acar C, Jebra VA, Portoghese M, et al. Revival of the radial artery for coronary artery bypass grafting. Ann Thorac Surg 1992; 54: 652-9; discussion 659-60.
3) Possati G, Gaudino M, Prati F, et al. Long-term results of the radial artery used for myocardial revascularization. Circulation 2003; 108: 1350-4.
4) Hata M, Yoshitake I, Wakui S, et al. Long-term patency rate for radial artery vs. saphenous vein grafts using same-patient materials. Circ J 2011; 75: 1373-7.
5) Tatoulis J, Buxton BF, Fuller JA, et al. Long-term patency of 1108 radial arterial-coronary angiograms over 10 years. Ann Thorac Surg 2009; 88: 23-9; discussion 29-30.
6) Collins P, Webb CM, Chong CF, et al. Radial artery versus saphenous vein patency randomized trial: five-year angiographic follow-up. Circulation 2008; 117: 2859-64.
7) Hosono M, Suehiro S, Shibata T, et al. Duplex scanning to assess radial artery suitability for coronary artery bypass grafting. Jpn J Thorac Cardiovasc Surg 2000; 48: 217-21.
8) da Costa FDA, da Costa IA, Poffo R, et al. Myocardial revascularization with the radial artery: a clinical and angiographic study. Ann Thorac Surg 1996; 62: 475-9; discussion 479-80.
9) Chen AH, Nakao T, Brodman RF, et al. Early postoperative angiographic assessment of radial grafts used for coronary artery bypass grafting. J Thorac Cardiovasc Surg 1996; 111: 1208-12.
10) Tranbaugh RF, Dimitrova KR, Friedmann P, et al. Coronary artery bypass grafting using the radial artery: clinical outcomes, patency, and need for reintervention. Circulation 2012; 126: S170-5.
11) Khot UN, Friedman DT, Pettersson G, et al. Radial artery bypass grafts have an increased occurrence of angiographically severe stenosis and occlusion compared with left internal mammary arteries and saphenous vein grafts. Circulation 2004; 109: 2086-91.
12) Tranbaugh RF, Dimitrova KR, Lucido DJ, et al. The second best arterial graft: a propensity analysis of the radial artery versus the free right internal thoracic artery to bypass the circumflex coronary artery. J Thorac Cardiovasc Surg 2014; 147: 133-42.
13) Aldea GS, Bakaeen FG, Pal J, et al. The society of thoracic surgeons clinical practice guidelines on arterial conduits for coronary artery bypass grafting. Ann Thorac Surg 2016; 101: 801-9.
14) Schwann TA, Zacharias A, Riordan CJ, et al. Sequential radial artery grafts for multivessel coronary artery bypass graft surgery: 10-year survival and angiography results. Ann Thorac Surg 2009; 88: 31-9.
15) Zacharias A, Habib RH, Schwann TA, et al. Improved survival with radial artery versus vein conduits in coronary bypass surgery with left internal thoracic artery to left anterior descending artery grafting. Circulation 2004; 109: 1489-96.
16) Emir M, Kunt AG, Çiçek M, et al. Sequential radial artery for coronary artery bypass grafting: five-year follow-up and evaluation with multi-detector row computed tomography. Cardiovasc Revasc Med 2012; 13: 272-6.
17) Li J, Liu Y, Zheng J, et al. The patency of sequential and individual vein coronary bypass grafts: a systematic review. Ann Thorac Surg 2011; 92: 1292-8.
18) O’Neill MJ, Wolf PD, O’Neill TK, et al. A rationale for the use of sequential coronary artery bypass grafts. J Thorac Cardiovasc Surg 1981; 81: 686-90.
19) Nakajima H, Kobayashi J, Tagusari O, et al. Functional angiographic evaluation of individual, sequential, and composite arterial grafts. Ann Thorac Surg 2006; 81: 807-14.
20) Nakajima H, Kobayashi J, Toda K, et al. Determinants for successful sequential radial artery grafting to the left circumflex and right coronary arteries. Interact Cardiovasc Thorac Surg 2011; 12: 125-9.
21) Desai ND, Naylor CD, Kiss A, et al. Impact of patient and target-vessel characteristics on arterial and venous bypass graft patency: insight from a randomized trial. Circulation 2007; 115: 684-91.
22) Deb S, Singh SK, Moussa F, et al. The long-term impact of diabetes on graft patency after coronary artery bypass grafting surgery: a substudy of the multicenter radial artery patency study. J Thorac Cardiovasc Surg 2014; 148: 1246-53; discussion 1253.
23) Miwa S, Desai N, Koyama T, et al. Radial artery angiographic string sign: clinical consequences and the role of pharmacologic therapy. Ann Thorac Surg 2006; 81: 112-8; discussion 119.
24) Shimizu T, Ito S, Kikuchi Y, et al. Arterial conduit shear stress following bypass grafting for intermediate coronary artery stenosis: a comparative study with saphenous vein grafts. Eur J Cardiothorac Surg 2004; 25: 578-84.
25) Hosono M, Shimizu Y, Takanashi S, et al. Early angiographic and clinical results of branch conduits attached proximally to left internal thoracic arteries. Ann Thorac Cardiovasc Surg 2002; 8: 145-50.
26) Merlo M, Terzi A, Tespili M, et al. Reversal of radial artery ‘string sign’ at 6 months follow-up. Eur J Cardiothorac Surg 2003; 23: 432-4.
27) Maniar HS, Sundt TM, Barner HB, et al. Effect of target stenosis and location on radial artery graft patency. J Thorac Cardiovasc Surg 2002; 123: 45-52.
28) Royse AG, Royse CF, Tatoulis J, et al. Postoperative radial artery angiography for coronary artery bypass surgery. Eur J Cardiothorac Surg 2000; 17: 294-304.
29) Gaudino M, Alessandrini F, Pragliola C, et al. Effect of target artery location and severity of stenosis on midterm patency of aorta-anastomosed vs. internal thoracic artery-anastomosed radial artery grafts. Eur J Cardiothorac Surg 2004; 25: 424-8.
30) Yoshida S, Numata S, Tsutsumi Y, et al. Short- and long-term results of radial artery and saphenous vein grafts in the right coronary system: a propensity-matched study. Surg Today 2017; 47: 335-43.