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# Literature review: Multi-vessel Coronary Artery Bypass Grafting

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*Abstract:* **Coronary artery bypass grafting (CABG) has developed rapidly in recent years as an important way to treat coronary heart disease. Among them, multi-vessel CABG is considered to improve the long-term patency rate of grafted vessels and improve the long-term quality of life of patients. main means. Although multi-arterial CABG has been generally carried out in developed countries such as Europe and the United States, multi-arterial CABG in China is still in its infancy, and it is only carried out in a few large heart centers in China. Therefore, through literature review, this article elaborates on multi-vessel CABG from three aspects: "patient selection", "characteristics of arterial grafts" and "bypass surgery strategy".**

*Keywords:* **coronary artery bypass grafting, multi-vessel coronary artery bypass grafting, arterial grafting, bypass strategy, patient selection.**

## 1. INTRODUCTION

In recent years, with the continuous development of the human economy and society and the continuous improvement of people's living standards, the incidence of coronary heart disease is also increasing. Coronary artery bypass grafting (CABG) is the most effective treatment for coronary heart disease, and its surgical volume and surgical techniques are constantly improving [1-2]. The so-called CABG is an operation to replace blocked coronary arteries to improve myocardial blood supply, relieve angina pectoris, improve quality of life, and reduce the risk of death from coronary heart disease. At present, the most commonly used coronary artery bypass graft material in the world is "left internal mammary artery (LIMA) + saphenous vein". However, in the 1980s, studies by Lytle et al. showed that the long-term patency rate of the internal mammary artery (IMA) was significantly better than that of the great saphenous vein [3-4]. The 10-year patency rate of the great saphenous vein is only 50-60%, while the 10-year patency rate of the internal mammary artery can be as high as 80-90% [5-6]. Therefore, since the 1990s, more arteries have been used for CABG, including the right internal mammary artery (RIMA), radial artery (RA), right gastroepiploic artery, etc., which further reduces the long-term mortality of CABG patients, the main serious Cardiovascular and cerebrovascular event (MACCE) incidence and risk of repeat revascularization. In recent years, the field of coronary surgery has begun to advocate the use of bilateral internal mammary artery (BIMA), RA, right gastroepiploic artery, and other bypass vessels for multi-arterial CABG, and even put forward the concept of total arterial CABG, to achieve better Good long-term graft patency rate and clinical prognosis [7-8]. Therefore, through literature review and clinical experience, this paper expounds on multi-arterial CABG from the aspects of "patient selection", "arterialized CABG grafting", "bypass surgery strategy", and "future and prospect".

## 2. PATIENT CHOICE

Locker et al. analyzed the factors affecting the long-term survival rate of patients with multi-vessel CABG and found that: advanced age, low ejection fraction, diabetes, chronic obstructive pulmonary disease, peripheral vascular disease, cerebrovascular accident, left main stenosis greater than 50%, non-specific Cardiopulmonary bypass is an independent prognostic factor [9]. Therefore, in 2011, the American College of Cardiology and the American Heart Association recommended the use of total arterial CABG in patients younger than 60 years old (class IIb recommendation, level of

evidence C) [1]; of patients using BIMA (class IIa evidence, level B recommendation) [2], but no specific age limit was made. The 2019 "Chinese Expert Consensus on Arterial Coronary Arterial Bypass Grafting 2019 Edition" recommends the use of multi-arterial and total arterial CABG in patients aged <65 years [10]. Based on the comprehensive analysis of the above-mentioned guideline recommendations and our center's experience in carrying out multi-vessel CABG, we believe that patients who meet the following conditions can be considered for multi-vessel bypass surgery:

● Patients under the age of 60 are given priority for multi-vessel CABG. Of course, multi-vessel CABG may also be considered for some patients under the age of 65 who are in the good physical condition and suitable for coronary artery disease;

● Patients with emergency surgery or other serious heart diseases that require simultaneous surgical correction are not suitable for multi-vessel CABG. Branch arterial CABG;

c. Patients with severe heart failure or other multiple organ dysfunctions before surgery are not suitable for multi-arterial CABG;

● Before surgery, it is necessary to investigate the vascular lesions of the proposed arterial bridge. In the presence of stenotic or occlusive lesions, multi-vessel CABG should be carefully selected.

Commonly used arterialized CABG grafts

At present, the commonly used arterial bridges for multi-arterial CABG are bilateral internal mammary arteries and radial arteries. Of course, there are also reports of using the right gastroepiploic artery, inferior epigastric artery, external circumflex femoral artery, etc. as vascular graft materials, but they are rarely used in general. The following are the commonly used internal mammary arteries and radial arteries:

**2.1 Internal Mammary Artery (IMA):**

2.1.1 Application status: The left internal mammary artery is the gold standard bypass vessel for CABG. Compared with the venous bypass vessel, it not only has the advantage of a high long-term patency rate but also has the advantages of improving survival and reducing MACCE. Therefore, except for rare contraindications, such as poor LIMA blood flow caused by left subclavian artery stenosis and serious risk of poor sternal union, LIMA should be routinely used as a bypass vessel for the anterior descending artery (LAD). Observational data reports: LIMA patency rate is about 98% in 1 year, 95% in 5 years, and still more than 90% in 10 years; RIMA patency rate is about 93% in 1 year, 90% in 5 years, and in 10 years still more than 80% [11]. And a large number of studies have shown that compared with unilateral internal mammary artery, the long-term survival rate and the incidence of MACCE in patients with CABG using BIMA are significantly improved [3,12]. Therefore, the current recommendations for the use of the internal mammary artery are: when the LAD requires revascularization, the IMA bypass vessel should be used unless there are contraindications (class I recommendation, level of evidence B); for suitable patients (non-sternal complications high risk ), the use of BIMA bypass vessels should be considered (class IIa recommendation, level of evidence B) [13-14]. However, the current use rate of LIMA in the North American thoracic surgery database exceeds 90%, while the use rate of BIMA is only 5%; the use rate of BIMA in Europe is slightly higher than that in North America, about 10%. The main reason for the low utilization rate of BIMA is poor postoperative sternum healing [15].

2.1.2 Key points of use: Poor healing of postoperative chest incision or infection of chest incision is an important reason that restricts the development of BIMA bypass surgery. To further reduce the incidence of poor thoracic incision healing or thoracic incision infection after BIMA bypass surgery, the following points should be noted:

● Studies have shown that diabetes is an independent risk factor for poor postoperative wound healing. We must pay attention to controlling blood sugar, and it is best to control the preoperative HbA1c below 6.5% (class I recommendation, level B evidence) [16];

● Use skeletalization techniques to obtain bilateral internal mammary arteries (class I recommendation, level B evidence). On the one hand, the free internal mammary artery using the skeletal technique can prolong the free length of the internal mammary artery, thereby making the anastomosis of the internal mammary artery easier; For chest wall injury, some branches of the internal mammary artery and internal mammary vein are preserved, which is beneficial to the healing of the postoperative chest incision [17-19];

● The sternum should be fixed firmly (class IIb recommendation, level C evidence). Good sternum fixation is the premise to promote sternum healing. Therefore, we recommend that patients under 50kg routinely use 5 wires to fix the sternum, and add a wire to fix the sternum for every 10kg of weight gain. If necessary, the "figure 8 fixation" can also be used to fix the sternum;

● Previous studies have shown that BMI>40kg/m2 is a high-risk factor for poor postoperative sternum healing. Therefore, BIMA bypass is not recommended for such patients [20].

● Smoking cessation (class I recommendation, level B evidence) [14].

**2.2 Radial artery (RA):**

2.2.1 Application status: Because RA is easy to obtain and the length is sufficient to reach the area of all coronary target vessels, RA is usually used as a supplement to ITA and is widely used in multi-vessel CABG. Observational data report that the patency rate of RA can exceed 95% at 1 year, 90% at 5 years, and still exceed 85% at 10 years [11]. And large-scale observational studies have shown that if the target vessel selection is appropriate, the 5-year patency rates of RA and RIMA are similar, and the composite cardiovascular events (including all-cause death, myocardial infarction, and revascularization) using RA and RIMA have no difference [21-23]. Therefore, the current recommendations for RA use are: as a supplement to IMA-LAD, RA bypass vessels should be used for coronary target vessels with severe proximal stenosis, and their patency and clinical outcomes are better than SVG (class I recommendation, grade B Evidence) [2,13]; however, the current use rate of RA in North America and Europe is only about 5%, the use rate of RA in Australia is higher than 10%, and the use rate of RA in China is 5.5%. There are two main reasons for the low utilization rate of RA: competing blood flow and bridge vasospasm [24].

2.2.2 Key points of use:

● Evaluation before radial artery acquisition: To avoid the excessive influence of the radial artery on the blood supply to the hand and the motor and sensory dysfunction of the hand, every patient who is going to undergo radial artery bypass is recommended. Before surgery, the blood supply of the hand and the patency of the radial artery should be fully evaluated. The most commonly used auxiliary examinations are Allen's test, dynamic Doppler ultrasound before and after RA occlusion, ambulatory blood pressure, or finger pulse oxygen saturation monitoring [25]. Allen's experiment: After making a fist, artificially pressurized and blocked the blood flow of the radial artery and the ulnar artery until complete ischemia of the hand was observed, and then the ulnar artery was relaxed, and the time required for the palm to fully recover its color was recorded. If the time is less than 6s, the Allen test is negative, and the radial artery can be obtained; if the time is greater than 6s, the test is positive and the radial artery cannot be obtained. Of course, many studies have shown that the Allen test has false-positive and false-negative results. Therefore, people began to try to use the finger pulse oxygen saturation monitoring method to assess the blood supply of the forearm [26].

The so-called finger pulse oximetry refers to recording the changes in blood oxygen saturation in the area supplied by the radial artery by placing a digital oximeter on the thumb. After blocking the radial artery and the ulnar artery, the normal blood oxygen saturation will be interrupted, and the ulnar artery will be released immediately. If the normal blood oxygen saturation curve cannot be restored, it indicates that the communication between the radial artery and the ulnar artery has not been restored, and the radial artery cannot be obtained. Dynamic Doppler ultrasound: A Doppler ultrasound probe is placed on the third metacarpal head to directly measure blood flow in the superficial palmar arch [27]. The continuous attenuation of the Doppler sound signal at the superficial palmar arch after compression of the radial artery indicates insufficiency of the ulnar artery [28-31].

● The contraindications of the radial artery as a graft vessel are mainly anatomical variation, radial artery calcification (or stenosis), and traumatic damage to the radial artery. The so-called anatomical variation mainly refers to the abnormal alignment of the radial artery, which makes it more difficult to obtain, or the severe dysplasia of the radial artery makes it unusable [32]; studies have shown that the incidence of calcification in the radial artery is significantly higher than that in the internal mammary artery, and the calcification rate of the radial artery is significantly higher than that of the internal mammary artery can be as high as 13%. Therefore, if the radial artery is calcified and narrowed, it should not be used as a graft material [33]; the most common traumatic injury to the radial artery is iatrogenic, such as radial artery puncture and placement of a piezometric tube for monitoring arterial blood pressure, radial artery puncture for coronary angiography or coronary intervention, etc[34-35]. Therefore, once the patient intends to undergo radial artery bypass grafting, the

invasive operation of the radial artery should be minimized. When obtaining the radial artery, the non-handed side and the non-injured side should be selected as far as possible. Of course, to make the operation more convenient, the left radial artery is preferred.

● Acquisition technology of radial artery: The smooth muscle of the radial artery wall is well developed, which is prone to spasms. Therefore, from the beginning of obtaining the radial artery, attention should be paid to avoiding radial artery injury, reducing direct stimulation of the radial artery, and trying to avoid radial artery spasms. RA is mostly obtained by open incision, using the "no-touch technique" (class I recommendation, level C evidence ) [2,13], using low-power electrocautery or ultrasonic scalpel to obtain as little mechanical or thermal stimulation of the radial artery as possible [36];

● Antispasmodic strategy for radial artery (class IIa recommendation, level C evidence): Since most radial arteries are harvested with arterial spasm, they cannot be directly used for CABG [37]. The risk period of RA spasm is the time of intraoperative acquisition and the early postoperative period, so after the intraoperative acquisition of RA, it should be immersed in a special antispasmodic liquid (the common formula of this liquid is papaverine + heparinized blood, or added vitamin A). Lapamil, nicardi, and other calcium ion antagonists)[38-39], calcium ion antagonists are often used intravenously after surgery or combined with nitrate anticonvulsants, among which calcium ion antagonists are recommended to be used for several weeks to several months[40]. Other less commonly used antispasmodics include milrinone, papaverine, and phenoxybenzamine. The biggest side effect of using the above antispasmodic drugs is hypotension, so attention should be paid to monitoring the blood pressure changes of patients when using antispasmodic drugs.

● Management of competing blood flow: Competing blood flow is one of the main causes of RA graft failure.

In addition, severe competitive blood flow can lead to the "line-like sign" of the graft vessel, that is, the overall diffuse stenosis of the vascular graft, which does not respond to vasodilator drugs. Moreover, the reversal of the RA line-like sign is extremely rare, and such grafted vessels have lost their function and should be classified as occluded vessels [41]. Studies have shown that when the target vessel of the RA artery bridge is moderately narrowed, the patency rate after the anastomosis is lower than when the target vessel is severely narrowed. Therefore, the thickness of the target blood vessel should be comprehensively considered when selecting the target blood vessel for RA.

The 2011 American College of Cardiology and American Heart Association (ACC/AHA) guidelines state that RA should only be considered for target vessels of the right main coronary artery with stenosis greater than or equal to 90% and target vessels of the left coronary system with stenosis greater than 70% as a bypass vessel. The 2016 STS and 2018 European Society of Cardiology and European Society for Cardiothoracic Surgery (ESC/EACTS) guidelines update recommended RA for severely stenotic coronary target vessels [2,13].

## 3. SURGICAL STRATEGIES FOR ARTERIAL BYPASS GRAFTING

3.1 Application status: Multi-vessel CABG refers to the use of two or more arterial bypass vessels to reconstruct important or wide blood supply target vessels, and the use of the great saphenous vein to reconstruct lesser target vessels to achieve multi-vessel coronary artery disease revascularization. Total arterialized CABG means that all bypass vessels are made of arterial vascular material. The use of multi-arterial CABG was better in RCT studies, such as 26% in the SYNTAX study [44] and as high as 21% in the FREEDOM study. The latest data from STS showed that compared with LIMA+SVG, patients with multi-vessel CABG using BIMA or LIMA+RA had no significant increase in mortality within 30 days after surgery [45].

However, patients using BIMA had a higher incidence of poor postoperative chest healing. This indicates that the use of multi-vessel CABG is safe in the perioperative period, and the use of BIMA requires a more careful selection of patients (excluding high-risk patients with the poor sternal union), while the use of IMA+RA requires relatively fewer patient conditions and surgical techniques. Most retrospective studies have shown that the patency rate, survival rate, and cardiac function of patients with multi-vessel CABG are significantly better than those of patients with single-vessel CABG 5-7 years after surgery [46]. In addition, some observational studies have shown that the long-term survival rate of patients with total arterial bypass grafting is better than that of patients without total arterial bypass grafting, but there is no multicenter randomized controlled trial to verify this conclusion [47]. The current use of multi-arterial CABG is close to 50% in Australia, about 12% in Europe, about 7% in North America, and about 6.3% in China.

3.2 Choice of surgical strategy: what kind of patients are suitable for arterial CABG? How to choose between multivessel CABG and total arterial CABG?

(1) Although many retrospective studies have shown that patients under the age of 70 can still obtain a good long-term patency rate and long-term survival rate by receiving multi-vessel graft CABG [48]. However, the median age at which BIMA and RA were applied in the US STS database was only 59 and 61 years. Based on the living standards and average life expectancy of Chinese residents, Chinese experts recommend multi-vessel CABG for those patients who are relatively young (less than or equal to 65 years old) and have a long life expectancy.

Secondly, the good cardiac function of patients is a necessary prerequisite; for those patients with emergency bypass surgery or patients with heart failure caused by chronic coronary heart disease, multi-vessel CABG or total arterial CABG is not recommended due to the high risk of bypass surgery[10].

Thirdly, arterialized CABG may be considered for patients with left main and/or multivessel coronary artery disease; patients with severe coronary target vessel disease and good distal vessel conditions should consider multivessel or even whole arterial CABG (Class IIa). recommendation, level of evidence C) [2,13]. Other factors to be considered include: whether the patient has severe heart disease requiring concurrent surgical treatment, the surgeon's own surgical experience, and surgical technique and whether the patient has systemic multiple organ dysfunction, etc.

(2) There is no unified conclusion on how to choose between multi-vessel CABG and total arterial CABG. The guidelines recommend that more arterial bypass should be selected based on the patient's conditions, target vessel characteristics, and operator experience. Vascular (Class I, Level of Evidence C) [2,13]. Although total arterial CABG has a high long-term effect, after all, it has a higher surgical technique and the patient's conditions, so it should not be carried out blindly. The author believes that multi-arterial CABG should be promoted to reduce the risk of surgery, and it is also suitable for some patients. Total arterial CABG can be performed.

## 4. FUTURE AND PROSPECTS

In the past 50 years, CABG surgical technology has developed rapidly, and both the number of surgical cases and the surgical effect have been greatly improved. LIMA-LAD serves as the "gold standard" for CABG surgery. However, there is still a lack of solid evidence-based medical evidence for the use of second artery grafts and even the development of total arterial CABG. Although many observational studies and retrospective analyses have confirmed the advantages of multi-arterial and total arterial CABG, there is still a lack of confirmation from multicenter randomized controlled studies. Therefore, our future work should do the following:

(1) Actively build a heart disease diagnosis and treatment team including cardiologists, cardiac surgeons, imaging diagnostic doctors, and intensive care doctors. The treatment of coronary heart disease is no longer a matter of a single department of cardiology or cardiac surgery but should be considered by the entire heart disease diagnosis and treatment team. Therefore, the guidelines recommend that the possibility of using arterial bypass vessels (including the number, type, and selection of target vessels) should be used as part of the cardiac team to discuss the revascularization plan (class I recommendation, level C evidence) [10];

(2) Positive participation in international scientific research cooperation, carrying out high-quality clinical research, and finding solid evidence-based medical evidence for multi-vessel CABG or total arterial CABG;

(3) Personalized surgical plan: The patient's coronary artery should be comprehensively considered when formulating a surgical plan

(4) Encourage competent heart centers to carry out various training, communication, and promotion activities on arterialized CBAG;

(5) Improve the quality control and evaluation system, connect arterial bypass vessels, and use ratio as a key metric.

## 5. CONCLUSION

In recent years, multi-arterial CABG and total arterial CABG have become the focus of coronary surgery. These two types of procedures have brought good long-term patency and survival rate of grafts to patients. Although this type of surgery has certain requirements on the patient's conditions and the operator's surgical technique, through the continuous efforts of everyone, arterialized CABG will be further popularized and optimized worldwide.

## REFERENCES

[1] Hillis LD, Smith PK, Anderson JL, et al. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery: a report of the American College of Cardiology Foundation / American Heart Association Task Force on Practice Guidelines[J]. Circulation, 2011, 124(23): e652-e735.

[2] Sousa-Uva M, Neumann FJ, Ahlsson A, et al. 2018 ESC /EACTS Guidelines on. myocardial revascularization[J]. Eur J Cardiothorac Surg, 2019, 55(1): 4-90.

[3] Lytle BW, Blackstone EH, Loop FD, et al. Two internal thoracic artery grafts are. better than one[J]. J Thorac Cardiovasc Surg, 1999, 117(5): 855-872.

[4] 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[J]. Circulation, 2004, 109(12): 1489-1496.

[5] Di Bacco L, Repossini A, Tespili MA, et al. Long-term follow - up of total. arterial versus conventional and hybrid myocardial revascularization：A propensity score matched analysis［J］. Cardiovasc Revasc Med,2019,20(1)：22-28

[6] Yanagawa B, Verma S, Mazine A, et al. Impact of total arterial revascularization on long term survival：A systematic review and meta-analysis of 130, 305 patients［J］. Int J Cardiol, 2017, 233：29-36.

[7] Taggart DP, Altman DG, Gray AM, et al. Randomized trial to compare bilateral. vs. single internal mammary coronary artery bypass grafting: 1-year results of the Arterial Revascularisation Trial (ART)[J]. Eur Heart J, 2010, 31(20):2470-2481.

[8] Gaudino M, Benedetto U, Fremes S, et al. Radial-artery or saphenous-vein grafts. in coronary-artery bypass surgery[J]. N Engl J Med, 2018, 378(22): 2069-2077.

[9] Locker C, Schaff HV, Dearani JA, et al. Multiple arterial grafts improve late survival of patients undergoing coronary artery bypass graft surgery: analysis of 8622 patients with multivessel disease[J]. Circulation, 2012, 126(9): 1023-1030.

[10] 中国动脉化冠状动脉旁路移植术专家共识组.中国动脉化冠状动脉旁路移植术专家共识 2019 版[J].中华胸心血管外科杂志, 2019, 35(4): 193-200.

[11] Frank WS, del Pedro JN, Scott JS. Sabiston ＆Spencer Surgery of The Chest. [M]. 8th ed, 2010:1413.

[12] Loop FD, Lytle BW, Cosgrove DM, et al. Influence of the internal mammary. artery graft on 10-year survival and other cardiac events [J]. N Engl J Med, 1986, 314(1):1-6.

[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 [J]. Ann Thorac Surg, 2016,101(2):801-809.

[14] Sousa-Uva M, Neumann FJ, Ahlsson A, et al. 2018 ESC/EACTS Guidelines on. myocardial revascularization [J]. Eur J Cardiothrac Surg, 2019,55(1):44-90.

[15] Hu X, Zhao Q. Skeletonized internal thoracic artery harvest improves prognosis. in high-risk population after coronary bypass surgery for good quality grafts [J]. Ann Thorac Surg, 2011,92(1):48-58.

[16] Rollins KE, Varadhan KK, Dhatariya K, Lobo DN. Systematic review of the. impact of HbA1c on outcomes following surgery in patients with diabetes mellitus. Clin Nutr, 2016, 35(2):308-316.

[17] Kamiya H, Akhyari P, Martens A, et al. Sternal microcirculation after skeletonized. versus pedicled harvesting of the internal thoracic artery: a randomized study. J Thorac Cardiovasc Surg, 2008,135(1):32-37.

[18] Gatti G, Maschietto L, Morosin M, et al. Routine use of bilateral internal. thoracic artery grafting in women: A risk factor analysis for poor outcomes. Cardiocasc revasc Med,2017,18(1):40-46.

[19] Hashimoto M1, Fukui T, Takanashi S. Bilateral Internal Thoracic Artery. Grafting: Is It Reasonable in Octogenarians? Ann Thorac Cardiovasc Surg,2015,21(5):452-458.

[20] Pettinari M, Sergeant P, Meuris B. Bilateral internal thoracic artery grafting. increases long-term survival in elderly patients. Eur J Cardiothorac Surg, 2015. 47(4): p. 703-9.

[21] Hayward PA, Gordon IR, Hare DL, et al. Comparable patencies of the radial. artery and right internal thoracic artery or saphenous vein beyond 5 years: results from the Radial Artery Patency and Clinical Outcomes trial [J]. J Thorac Cardiovasc Surg, 2010,139(1):60-65.

[22] Gaudino M, Benedetto U, Fremes S, et al. Radial-artery or saphenous vein grafts. in coronary artery bypass surgery [J]. N Engl J Med, 2018,378(22):2069-2077.

[23] 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]. J Thorac Cardiovasc Surg, 2014,147(1):133-140.

[24] Elbradissi AW, Aranki SF, Sheng S, et al. Trends in isolated coronary artery bypass grafting: an analysis of the Society of Thoracic Surgeons adult cardiac surgery database [J]. J Thorac Cardiovasc Surg, 2012,143(2):273-281.

[25] Habib J, Baetz L, Satiani B. Assessment of collateral circulation to the hand prior to radial artery harvest [J]. Vasc Med, 2012,17(5):352-361.

[26] Kaminski RW, Barnes RW. Critique of the Allen test for continuity of the palmar arch assessed by Doppler ultrasound. Surg Gyn Obst, 1976,142:861-864.

[27] Susumu Manabe, Noriyuki Tabuchi, Masaaki Toyama, et al. Oxygen pressure measurement during grip exercise reveals exercise intolerance after radial harvest. Ann Thorac Surg, 2004,77:2066-2070.

[28] Rodriguez E, Ormont ML, Lambert EH, et al. The role of preoperative radial artery ultrasound and digital plethysmography prior to coronary artery bypass grafting. Eur J Cardiothorac Surg, 2001,19:135-139.

[29] Dumanian GA, Segelman K, Mispireta LA, et al. Radial artery use in bypass grafting dose not change digital blood flow or hand function. Ann Thorac Surg, 1998,65:1284-1287.

[30] Chong WC, Ong PJ, Hayward CS, et al. Effects of radial artery harvesting on forearm function and blood flow. Ann Thorac Surg, 2003,75:1171-1174.

[31] Lee H-S, Chang B-C, Heo YJ. Digital blood flow after radial artery harvest for coronary artery bypass grafting. Ann Thorac Surg, 2004,77:2071-2074.

[32] Uglietta JP, Kadir S. Arteriographic study of variant arterial anatomy of the upper extremities. Cardiovasc Interven Radiol.1989,12:145-148.

[33] Valsecchi O, Vassileva A, Musumeci G, et al. Failure of transradial approach during coronary interventions: anatomic considerations. Catheter Cardiovasc Interv, 2006,67:870-878.

[34] Kamiya H, Ushijima T, Kanamori T, et al. Use of the radial artery graft after transradial catheterization: is it suitable as a bypass conduit? Ann Thorac Surg, 2003,76:1505-1509.

[35] Staniloae CS, Mody KP, Sanghvi K, et al. Histopathologic changes of the radial artery wall secondary to transradial catheterization. Vasc Health Risk Manag, 2009,5:527-532.

[36] Ronan JW, Perry LA, Barner HB, et al. Radial artery harvest: comparison of ultrasonic dissection with standard technique. Ann Thorac Surg, 2000,69:113-114.

[37] He GW, Taggart DP. Antispastic management in arterial grafts in coronary artery grafting surgery [J]. Ann Thorac Surg, 2016,102(2):659-668.

[38] He GW. Verapamil plus nitroglycerin solution maximally preserves endothelial function of the radial artery: comparison with papaverine solution [J]. J Thorac Cardiovasc Surg, 1998,115(6):1321-1327.

[39] He GW, Fan L, Furnary A, et al. A new antispastic solution for arterial grafting: nicardipine and nitroglycerin cocktail in preparation of internal thoracic and radial arteries for coronary surgery [J]. J Thorac Cardiovasc Surg,

2008,136(3):673-680, 680 e1-2.

[40] Patel A, Asopa S, Dunning J. Should patients receiving a radial artery conduit have post-operative calcium channel blockers? [J]. Interact Cardiovasc Thorac Surg, 2006,5(3):251-257.

[41] Miwa S, Desai N, Koyama T, et al. Radial artery angiographic string sign: clinical consequences and the role of pharmacologic therapy [J]. Ann Thorac Surg, 2006,81(1):112-118.

[42] Gao C, Manganas C, Horton M, et al. Angiographic outcomes of radial artery versus saphenous vein in coronary artery bypass graft surgery: a meta-analysis of randomized controlled trial [J]. J Thorac Cardiovasc Surg, 2013,146(2):255-261.

[43] Desai ND, Cohen EA, Naylor CD, et al. A randomized comparison of radial-artery and saphenous-vein coronary bypass grafts [J]. N Engl Med, 2004,351(22):2302-2309.

[44] Serruys PW, Morice MC, Kappetein AP, et al. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease [J]. N Engl J Med, 2009,360(10):961-972.

[45] Schwann TA, Habib RH, Wallace A, et al. Operative outcomes of multiple-arterial versus single-arterial coronary bypass grafting [J]. Ann Thorac Surg, 2018,105(4):1109-1119.

[46] Locker C, Schaff HV, Dearani JA, et al. Multiple arterial grafts improve late survival of patients undergoing coronary artery bypass graft surgery: analysis of 8622 patients with multivessel disease [J]. Circulation, 2012,126(9):1023-1030.

[47] Tatoulis J, Wynne R, Skillington PD, et al. Total arterial revascularization: achievable and prognostically effective-a multicenter analysis [J]. Ann Thorac Surg, 2015,100(4):1268-1275.

[48] tranbaugh RF, Schwann TA, Swistel DG, et al. Coronary artery bypass graft surgery using the radial artery, right internal thoracic artery, or saphenous vein as the second conduit [J]. Ann Thorac Surg, 2017,104(2):553-559.