Coronary Artery Surgery — Recent Developments

Kuan-Ming Chiu and Shu-Hsun Chu

Cardiovascular surgery had great advancement in the twentieth century. In 1929, Werner Forssman performed the first human cardiac catheterization on himself.[1] Then cardiac catheterization gradually became a gold standard in the diagnosis of congenital heart diseases as well as valvular heart diseases. In 1953, Gibbon set a milestone for cardiac surgery by invention of cardiopulmonary bypass. Mason Sones performed the first diagnostic coronary angiogram at Cleveland Clinic in 1958. Rene Favaloro did the first coronary artery bypass grafting (CABG) in 1967.[2] From then on, coronary artery diseases (CAD) have had excellent resolution. 1977 saw Andreas Gruentzig change the landscape by doing the first coronary angioplasty on an awake human.[3] Julio Palmaz and Richard Schatz pushed the advance further by invention of balloon expandable stents to address the issues of recoil and restenosis after balloon angioplasty. Cardiologists have modernized myocardial revascularization by much investment and great innovation. Percutaneous coronary intervention started to play a major role in the myocardial revascularization in the last two decades. The advent of new technologies provides many less invasive methods of myocardial revascularization, such as percutaneous transluminal coronary angioplasty (PTCA), stents, brachytherapy, intravascular ultrasound, rotablator, and drug-eluting stents.

Key Words: Coronary artery bypass • Off-pump • Endoscopic vessel harvest • Minimally invasive surgery

Minimally invasive surgery

Most cardiac patients prefer catheter-based intervention as their first choice rather than CABG. Cardiac surgeons should be aware of this trend and accommodate themselves to less invasive approaches. A shift to less invasive CABG is essential for surgeons to play an active role in the field of coronary revascularization. Patients proposed to have cardiac operations are concerned about having general anesthesia, longer hospital stay, longer post-operative recovery, delayed return to their jobs, and suffering surgery-related discomfort. They face higher operative morbidity and mortality to get the "better long-term outcome".[4] Thus, some people say that they would rather visit their dentist every 6 months than their cardiac surgeon every 10 years. Obviously, patients want their wounds to be smaller, hospital stay to be shorter, and risk of the procedure to be as low as possible. In order to play a better role in the arena of myocardial revascularization, the cardiac surgeon should be able to convince patients of all potential benefits achieved by CABG and reduce surgical drawbacks from the patients' points of view.

In the past decade, two approaches have been utilized to decrease the invasiveness of coronary artery bypass surgery: 1. elimination of cardiopulmonary bypass and cardioplegic arrest to decrease the systemic inflammatory response and eliminate global myocardial ischemia, and 2. minimization of access trauma through small incisions. Sternotomy remains the patient's major fear. Every patient wants the wound as small as possible. However, every surgeon prefers the procedures as simple and easy as possible, which demand a larger in-

Received: August 30, 2004 Accepted: March 30, 2005
Division of Cardiovascular Surgery, Cardiovascular Center, Far-Eastern Memorial Hospital, Pan-Chiao, Taipei, Taiwan.
Address correspondence and reprint requests to: Dr. Shu-Hsun Chu, Division of Cardiovascular Surgery, Cardiovascular Center, Far-Eastern Memorial Hospital, Pan-Chiao, Taiwan.
Tel: 886-2-8966-7000 ext. 1655; Fax: 886-2-8966-0906;
E-mail: chushsun@ms42.hinet.net

cision. Cardiac surgeons prefer everything under control and handheld. When every surgical subspecialty started to adopt the endoscopic procedures, cardiac surgeons remained conservative. Recently, more and more cardiovascular procedures have adopted the minimally invasive trend by creating smaller or alternative incisions. Coronary artery revascularization therefore could be tailored to every patient by the incisions of midline sternotomy, para-sternotomy, left anterior thoracotomy, subxyphoid incision, etc. These procedures are termed by their varied approaches as minimally invasive direct coronary artery bypass surgery (MIDCAB), subclavian/axillary artery to coronary artery bypass (SAXCAB), and endoscopically atraumatic coronary artery bypass (Endo-ACAB). These individualized and tailor-made procedures gain further acceptance by patients. However, minimally invasive surgery may not be thought of as a specific procedure, but as "a philosophy — a constellation of new routines, methods, and techniques all directed collectively toward speedily returning patients to normalcy".[5]

Off-Pump vs On-Pump

To apply a minimally invasive philosophy to cardiac surgery would require an operation-specific strategy. For example, in minimally invasive coronary bypass surgery, the desirable objective is to avoid extracorporeal circulation and its deleterious effects. The first successful coronary artery bypass surgery was performed on the beating heart in the early 1960s. This procedure was not widely adopted at that time due to technical challenges, inconsistent results, and limited applicability. The development of extracorporeal circulation and myocardial protective strategies created a safer, less technically challenging, still, bloodless surgical field. However, enabling technology like coronary stabilizers, apical suction devices, carbon dioxide mist delivery devices and intracoronary shunts provides a nearly motionless, bloodless surgical platform for the revival of beating heart coronary artery bypass surgery. In the last 50 years, off-pump coronary artery bypass (OPCAB) is the procedure with fastest adoption rate by cardiac surgeons in comparison with Beck procedure, Vineberg procedure, and conventional CABG. It has proceeded by CABG concept and proven safe and effective. Most hospitals doing CABG have readily adopted OPCAB. The procedures themselves have been standardized and rapidly duplicated worldwide. The Society of Thoracic Surgeon database shows the continued increase in the percentage of OPCAB in surgical coronary artery revascularization. It is growing even faster in the Third World. Thousands of articles have been published in the journals to discuss the advantages and disadvantages of extracorporeal circulation for coronary artery surgery[6,7]. Current consensus is that on-pump CABG has excellent results in the hands of the majority of surgeons, and OPCAB have excellent results in the hands of cardiac surgeons who perform the procedure routinely in their daily practice. The major benefit of OPCAB is demonstrated in high-risk patients, resulting in a lower incidence of stroke, embolic and inflammation mediated events such as renal and pulmonary insufficiency.[8] The lowered mortality of OPCAB was demonstrated primarily in the high-risk patients.[9,10] Quality of anastomoses will become the important issue to evaluate the long-term result.[11] OPCAB will become popular, but extracorporeal circulation is still the most powerful sword of the cardiac surgeon to circumvent all complex cases such as patients with poor ventricular function, huge heart size, or significant valvular disease. Fortunately, as we start to evaluate the drawbacks of CPB, current technologies provide better solutions.

Endoscopic harvest of graft conduits

For coronary artery surgery, bypass grafts are always necessary. Many surgeons have made great efforts to reduce the morbidities of graft donor sites. Endoscopy based on modern technologies has had tremendously impact in this area. Endoscopic vessel harvest of saphenous vein, radial artery, mammary artery and even gastro-epiploic artery has been achieved and become more and more popular in daily practice. These techniques provide patients cosmetic wounds, earlier ambulation, less suffering, and most important, equal quality of vein grafts.[12-16] These benefits would persuade both patients and surgeons to adopt the procedure as the medical standard. A recent published paper even showed equal 6-month patency rate of saphenous vein for CABG in a randomized trial of endoscopic versus open vein harvest.[17]

Arterial graft vs venous graft

The survival advantage of CABG over PTCA among

patients with diabetes and multivessel diseases suggests sustained graft patency. The long-term patency rate is achieved best by CABG compared with other interventions. Despite diabetic patients' having smaller distal vessels and vessels judged to be of poorer quality, diabetes does not appear to adversely affect patency of internal mammary artery or vein grafts over an average of 4-year follow-up.[18] Thus, how to provide a better graft to achieve the goal is a constant concern for cardiac surgeons. Much evidence has shown arterial conduits are much better than venous ones.[19,20] Internal mammary artery is the best choice, followed by radial artery and other less frequently used arteries.[21-23] The most recent data suggested patency at 10 years was 61% for saphenous vein grafts compared with 85% for internal mammary artery grafts. The 10-year patency for vein grafts was better and the 10-year patency for internal mammary artery grafts was worse than expected.[24] Along with the recent advance of medications, like antiplatelet agents and statins, improved bypass graft patency in the future will be hopefully expected. However, the increasing use of arterial conduits is the trend and will benefit our patients.

Cerebral embolization

Cerebral embolization has been the major risk of cardiovascular surgery. Although OPCAB decreases the incidence of cerebral events, aortic manipulation still remains a concern, especially during clamping.[25] Proximal connectors like Medtronic Spyder anastomotic devices allow aorto-saphenous anastomosis in one shot. These minimize the need for aortic clamping. Proximal seal systems like Guidant Heartstring devices allow surgeons to construct a hand-sewing anastomosis without clamping the ascending aorta. Furthermore, some surgeons have begun to adopt the "aorta no-touch" principle which has further decreased embolic events.[26] For instance, left internal mammary artery and Y extension with radial artery construct total arterial revascularization. However, the long-term patency of these configurations and whether the flow reserve meets the myocardial demand require further clinical observation. Other coronary bypasses derived from subclavian artery or descending aorta in an exra-anatomic way further decrease the incidence of stroke.

Intraoperative conduit confirmation

In past decades, all the coronary bypass grafts were assumed to be patent immediately after surgery. However, technical errors still contributed to early graft failure in a significant number of cases. In current practice, plastic surgeons show impressive results by providing images before and after procedures. Interventional cardiologists show coronary angiograms before and after PTCA. To see is to believe. How can we cardiac surgeons persuade our patients we have done the best merely by their trust or our reputation? Therefore, today's cardiac surgeons should be able to convince patients what they have achieved in the operation theater. Intra-operative conduit confirmation has become the necessity. Current technologies involving color Doppler ultrasound, electromagnetic flow measurement, transit time flow measurement, and angiography have been applied for this purpose. In most circumstances, intra-operative conduit confirmation serves as a gatekeeper and ensures the graft patency. Meanwhile, it provides the foundation of trust between patients and surgeons. Also, evidence-based data can be collected to evaluate the graft patency of any particular cohort.

Robotic surgery

Robots in cardiovascular surgery show promise. Robotic systems have been recently refined for use in cardiac surgery to facilitate different surgical procedures. These systems enhance precision through endoscopic approaches by computerization, digital interface, and telemanipulation technology. They provide excellent visualization of operative fields. Electronic arms allow for great maneuverability with stability. Although several groups have demonstrated the feasibility of totally endoscopic coronary artery bypass (TECAB) with robotic systems, there remain significant challenges to further development and unanswered questions regarding efficacy, patency and appropriate application. More than one-third of patients were converted intraoperatively to an open, manual procedure, and most of the reported cases received single-vessel bypass procedures only. Robotic-assisted closed-chest coronary artery bypass is currently confronting the limitations of enabling technology. There are challenges to be overcome before widespread application of off-pump multivessel TECAB surgery.[27] Recently developed anastomostic facilitators like magnetic vascular positioner devices are simple yet effective and timesaving techniques for anastomotic coupling.[28] With the continuous progress of essential enabling technology like an-

astomostic facilitators, robotic intervention will play a role in the detailed handicraft of cardiac surgeons in the future. Before the implementation of robotic program, the safe introduction of totally endoscopic coronary artery bypass grafting using a stepwise and modular approach should always be emphasized.[29]

Fast track for cardiac surgery

"Fast track" programs have been introduced to shorten the stay in intensive care unit and hospital. All strategies toward less invasiveness result in less morbidity and earlier discharge from hospital than conventional CABG. Medical cost saving is another significant issue. Continuous and coordinated progress in pre-operative, intra-operative, and post-operative management would provide greatest benefit for patient care.

Non-invasive modalities for CAD diagnosis

Diagnoses of coronary artery disease (CAD) in the future will be made by non-invasive modalities such as high-resolution multi-slice computed tomography, electronic beam tomography and magnetic resonance imaging, etc. These will change the role of interventional cardiologists who would not otherwise be able to control the patient flow in decisions regarding intervention. That means patients will have a diagnosis of CAD by non-invasive modalities and then start to seek further therapeutic interventions. By that time, who provides the best choice for patients will win the contest. However, cardiac surgeons who are capable of performing percutaneous, endovascular interventions would provide the total solution for cardiac patients in a single visit. Before this possibility comes into reality, hybrid procedures from interventional cardiologists and cardiac surgeons would be the excellent alternative choice for most CAD patients.[30]

Pharmacological advances

Following the great pharmacological advances, cardiac surgeons have the responsibility to learn more from current evidence-based management of coronary disease. New antiplatelet agents, glycoprotein IIb/IIIa antagonists, and angiotensin receptor antagonists all play an important role in the treatment of variable spectrum CAD patients. Beyond surgical procedures, meticulous clinical follow-up and pharmacological adjustment to prevent graft occlusion and progression of native CAD ensure the best results of CABG.[31]

Current status of coronary artery surgery in Taiwan

Cardiac surgeons in Taiwan work very hard to keep pace with the pioneers. In past three years, according to the Taiwan Society of Thoracic and Cardiovascular Surgeons database, OPCAB has reached more than 50% of isolated CABG. Endoscopic graft conduit harvest was widely adopted and comprised of one third of total saphenous vein harvest in Taiwan. More than 90% of patients who underwent CABG had at least one arterial graft. Sternum-sparing and minimal-access CABG became popular. Cardiac surgeons are aware of the importance of confirmation of graft patency. All these kinds of progresses better serve patients' interest.

Cardiac surgery has shown great technological improvements over the past decades. However, impact of interventional technology, impact of new surgical procedures, hospital and surgeon CABG volume, change in patient risk category, reduced hospital resources, and reduced industry interest in cardiac surgery are all our concerns in the future of surgical revascularization. Dennis Jones said, "The history of surgery is a history of obsolete operations". By innovation and retraining, surgeons can still insure their places in the management of cardiovascular diseases. Technological advances make coronary surgery less invasive, less morbid, less expensive, and more durable. To survive the test of time, cardiac surgeons need constant retraining to adopt the continuously evolving new techniques. As Darwin said, "It is not the smartest or the strongest species that survive, but the most adaptable ones that do".

REFERENCES

1. Forssman W. Die Sondierung des rechten Herzens Berl Klin Wochenschr 1929;8:2085-7.
2. Favaloro R. Direct and indirect coronary surgery. *Circulation* 1972;46(6):1197-207.
3. Gruentzig AR, Senning A, Siegenthaler WE. Nonoperative dilatation of coronary artery stenosis: percutaneous transluminal coronary angioplasty. *N Engl J Med* 1979;301:61-8.
4. Bypass Angioplasty Revascularization Investigation (BARI) Investigators. Comparison of coronary bypass surgery with

angioplasty in patients with multivessel disease. *N Engl J Med* 1996;335:217-25.
5. Chitwood WR Jr, Gulielmos V: What is minimally invasive cardiac surgery? *CTSnet Web Site*. 2003.
6. Reston JT, Tregear SJ, Turkelson CM. Meta-analysis of short-term and mid-term outcomes following off-pump coronary artery bypass grafting. *Ann Thorac Surg* 2003;76(5):1510-5.
7. Khan NE, De Souza A, Mister R, et al. A randomized comparison of off-pump and on-pump multivessel coronary-artery bypass surgery. *N Engl J Med* 2004;350:21-8.
8. Newman MF, Kirchner JL, Phillips-Bute B, et al. Longitudinal assessment of neurocognitive function after coronary-artery bypass surgery. *N Engl J Med* 2001;344:395-402.
9. Nathoe HM, van Dijk D, Jansen EWL, et al. A comparison of on-pump and off-pump coronary bypass surgery in low-risk patients. *N Engl J Med* 2003;348:394-402.
10. Mack MJ, Magee MJ, Dewey TM, et al. Neurocognitive function after coronary-artery bypass surgery. *N Engl J Med* 2001;345: 543-5.
11. MacGillivray TE, Vlahakes GJ. Patency and the pump-the risks and benefits of off-pump CABG. *N Engl J Med* 2004;350:3-4.
12. Allen KB, Griffith GL, Heimansohn DA, et al. Endoscopic versus traditional saphenous vein harvesting: a prospective, randomized trial. *Ann Thorac Surg* 1998;66(1):26-32.
13. Schurr UP, Lachat ML, Reuthebuch O, et al. Endoscopic saphenous vein harvesting for CABG: a randomized, prospective trial. *Thorac Cardiovasc Surg* 2002;50(3):160-3.
14. Genovesi MH, Torrillo L, Fonger J, et al. Endoscopic radial artery harvest: a new approach. *Heart Surg Forum* 2001; 4(3):223-5.
15. Felisky CD, Paul DL, Hill ME, et al. Endoscopic greater saphenous vein harvesting reduces the morbidity of coronary artery bypass surgery. *Am J Surg* 2002;183(5):576-9.
16. Bonde P, Graham AN, MacGowan SW. Endoscopic vein harvest: advantages and limitations. *Ann Thorac Surg* 2004;77(6):2076-82.
17. Yun KL, Wu YX, Aharonian Y, et al. Randomized trial of endoscopic versus open vein harvest for coronary artery bypass grafting: six-month patency rates. *J Thorac Cardiovasc Surg* 2005;129(3):496-503.
18. Schwartz L, Kip KE, Frye RL, et al. Coronary bypass graft patency in patients with diabetes in the bypass angioplasty revascularization investigation (BARI). *Circulation* 2002;106(21): 2652-8.
19. Barner HB, Sundt TM 3rd. Multiple arterial grafts and survival. *Curr Opinion Cardiol* 1999;14(6):501-5.
20. Beghi C, Nicolini F, Budillon AM, et al. Midterm clinical results in myocardial revascularization using the radial artery. *Chest* 2002;122(6):2075-9.
21. Dargie HJ. Late results following coronary artery bypass grafting. *Eur Heart J* 1992;13(Suppl H):89-95.
22. Tatoulis J, Buxton BF, Fuller JA, et al. Total arterial coronary revascularization: techniques and results in 3,220 patients. *Ann Thorac Surg* 1999;68(6):2093-9.
23. Royse AG, Royse CF, Tatoulis J. Total arterial coronary revascularization and factors influencing in-hospital mortality. *Eur J Cardio-Thorac Surg* 1999;16(5):499-505.
24. Goldman S, Zadina K, Moritz T, et al. Long-term patency of saphenous vein and left internal mammary artery grafts after coronary artery bypass surgery: results from a Department of Veterans Affairs cooperative study. *J Am Coll Cardiol* 2004; 44(11):2149-56.
25. Sharony R, Bizekis CS, Kanchuger M, et al. Off-pump coronary artery bypass grafting reduces mortality and stroke in patients with atheromatous aortas: a case control study. *Circulation* 2003; 108(suppl 1):II15-20.
26. Kobayashi J, Sasako Y, Bando K, et al. Multiple off-pump coronary revascularization with "aorta no-touch" technique using composite and sequential methods. *Heart Surg Forum* 2002; 5(2):114-8.
27. Magee MJ, Mack MJ. Robotics and coronary artery surgery. *Curr Opinion Cardiol* 2002;17(6):602-7.
28. Falk V, Walther T, Stein H, et al. Facilitated endoscopic beating heart coronary artery bypass grafting using a magnetic coupling device. *J Thorac Cardiovasc Surg* 2003;126(5):1575-9.
29. Bonatti J, Schachner T, Bernecker O, et al. Robotic totally endoscopic coronary artery bypass: program development and learning curve issues. *J Thorac Cardiovasc Surg* 2004;127(2): 504-10.
30. Cisowski M, Morawski W, Drzewiecki J, et al. Integrated minimally invasive direct coronary artery bypass grafting and angioplasty for coronary artery revascularization. *Eur J Cardio-Thorac Surg* 2002;22(2):261-5.
31. Rosenfeldt FL, He GW, Buxton BF, et al. Pharmacology of coronary artery bypass grafts. *Ann Thorac Surg* 1999;67(3): 878-88.

Review Article **Acta Cardiol Sin 2005;21:131–6**

冠狀動脈手術 — 近來發展

邱冠明　朱樹勳
台北縣 亞東紀念醫院　心臟血管外科

心臟外科的手術在 1953 年 Dr. Gibbon 發明心肺機之後就有長足的進步, 在 1960 年代末期，繞道手術的成功奠定了外科在冠心症的治療的重要地位。直到 1980 年代，冠狀動脈氣球擴張術和支架置放術的發明，重新改寫了冠心症治療的流程。隨著新科技的演進，冠狀動脈的手術也有新的進展。微創手術是所有外科的共同趨勢，繞道手術自然不能例外，除了縮小傷口，避免胸骨的切開以外，最重要的是去除體外循環的可能危害，因此在新科技的協助之下，不停跳的繞道手術逐漸普及，雖然使用心肺機與否的優缺點仍有爭議，但越來越多支持的証據和手術個案卻是事實。此外，內視鏡的引進和機械手臂都是微創的延伸，而內視鏡血管摘取術也成為減少術後併發症和改善滿意度的重要環節。實証醫學的資料顯示，繞道手術中動脈移植較靜脈移植佳，許多新葯物的使用也可延長長期的暢通率，更加改善冠心症的外科治療成績。從病患的觀點出發，在術中確認血管吻合的成效，以 fast track 使患者提早恢復，盡一切可能減少繞道手術後出現腦血管意外的風險，都是近年來重要的品質指標。在面臨更多挑戰的未來，心臟外科醫師有責任以最低的風險，提供更好的治療成績，以符合患者的期望。

關鍵詞：冠狀動脈繞道、不停跳、內視鏡血管摘取、微創手術。