The Alternatives of Autologous Arterial Grafts for Coronary Bypass Surgery

Shi-Min Yuan, Amihay Shinfeld, Erez Kachal and Ehud Raanani

A survey is made to autologous arterial grafts for coronary arterial bypass grafting.

Articles were collected by searching MEDLINE database. Search terms included arterial graft and coronary bypass. Reports regarding the commonly used arterial grafts, including the internal mammary artery (IMA), as well as the radial, right gastroepiploic, and inferior epigastric arteries, were screened in order to highlight their morphologic characteristics, patency rates, advantages and drawbacks, while a comprehensive collection was made on those grafts with merely a scattering of cases, such as the subscapular, ulnar, splenic, and lateral costal arteries.

The patency rate of pedicled left and right IMAs were similar. Pedicled IMA had a higher patency than free IMA graft. Higher incidence of sternal infection was found in patients with bilateral IMAs bypassed. A skeletonized IMA would supply a better sternal perfusion, but may cause a focal injury during harvest. An increased risk of graft failure of the IMA is associated with grafting low-grade stenosed or non-left anterior descending coronary arteries. The superiority of the IMA over other conduits might be due to its superior endothelial function and flow remodeling. The IMA is elastic, while others are muscular. The patency rates were 88.9% for the IMA at 20-year, 85% for the radial artery at 5-year, 85.7% for the right gastroepiploic artery at 5-year, and 52.2% for the inferior epigastric artery at 21.2-month follow-up, respectively. Other grafts had fewer reports, but showed good results.

In the graft selection for coronary bypass, the primary choice is the left IMA; the second choice is the right IMA; and the radial artery is the third choice. Other arteries could be used as additional grafts.

INTRODUCTION

Inspired by the potential advantage of the internal mammary artery (IMA) as a graft conduit for coronary bypass surgery, an intensified search for new alternative autologous arterial grafts has been motivated, thereby satisfying the requirements of the increasing numbers of repeated bypass operations and total arterial coronary revascularizations. Arteries differ from each other in terms of anatomy and histology. They have resulted in various clinical outcomes, and are playing different roles in coronary bypass surgery as graft conduits. Thus, a complete survey of the arterial grafts is necessary.

THE ARTERIAL GRAFTS

The IMA

Single IMA has been used as a coronary bypass graft since the 1960's.[1,2] This technique was popularized by Green and colleagues,[3] who introduced magnification to improve the precision of suturing the anastomoses. The use of bilateral IMA grafts was first reported by Suzuki and associates[4] in 1973. The mean usable length of the IMA averages 13.2 cm,[5] and in 90% of cases, the IMA is very good with regard to its lumen and flow,[6] so that it

matches almost exactly the size of the LAD.[7] Routine postmortem microscopic examinations showed 4.2% of patients with either atherosclerotic coronary or minimal atherosclerotic heart diseases had atherosclerotic narrowing in IMA (25% < reduction in lumen diameter < 50%). The branches of the IMA showed more atherosclerosis than the parent vessel, and the bifurcating areas were the major sites of luminal narrowing.[8] The incidence of intimal hyperplasia in the IMAs was as low as 29.6%.[9] Only 14% of patients 5 years after surgery demonstrated progression of atherosclerosis or new atherosclerosis in the coronary arteries distal to the anastomoses.[10] A morphologic study discovered that the superiority of the IMA over other conduits may be due to its blood supply from the vasa vasorum, in addition to its well-developed internal elastic membrane, its innervation, and a comparatively low number of smooth muscle cells in its media.[11] The superior endothelial function of the IMA has been well documented as an important determinant of arterial remodeling.[12]

In the past, many surgeons avoided using IMA graft in elderly patients given that no substantial benefit existed for patients with a limited long-term outcome and greater risks of noncardiac complications.[13] However, by affording improved early and late survival, one case control study supported routine left IMA grafting in patients older than 70 years requiring coronary bypass.[14] Clinical indications for bilateral IMAs are younger and non-diabetic patients.[15] Bical et al.[16] extended the indication for bilateral IMA grafting to middle-aged diabetic patients. A skeletonized IMA would preserve collateral blood flow and supply a better sternal perfusion after harvesting, especially in obese and diabetic patients.[17] If FEV_1 is lower than 1100 mL, bilateral IMA grafting would not be undertaken.[17] Nevertheless, debates still exist with regard to the prediction of IMA size, such as whether to use single or bilateral IMAs in individuals with hypertension or a large barrel-chest who have extremely large IMAs.[18]

Free IMA grafts have been used to reach more distal areas of the native coronary arteries and to avoid inadequate length, acute angulation and excessive tension of the graft.[18] In general, the left IMA was used to graft the LAD; the free right IMA was used to reach any of the coronary arteries, the most common being the first or second marginal branch. Tector et al.[19] pioneered ana-

stomosing the proximal end of free right IMA to in situ left IMA as a T-graft for complete arterial myocardial revascularization in patients with triple-vessel disease. No spasm of free right IMA was noted at or after operation.[20]

In situ bilateral IMA grafts have three basic arrangements: 1. to graft the left IMA to the LAD and the right IMA to the right coronary artery; 2. to graft the left IMA to the LAD and route the right IMA to the circumflex branches through the transverse sinus; and 3. to place the right IMA anterior to the LAD, and graft the left IMA to a circumflex branch.[21] Pedicled right IMA through the transverse sinus does not easily reach the distal marginal branch, and the graft tends to be stretched. It is difficult to check the bleeding. Placing the pedicled right IMA anterior to the aorta creates potential injury at a reoperation.[20]

Major sternal infection was reported in up to 4% of patients having bilateral IMAs especially in diabetic females or patients with postcardiotomy low output syndrome.[22] The rate of sternal wound infections is higher when both IMAs are used, but appears to decrease when the IMAs are skeletonized.[23] Hypoperfusion by IMA grafts was noted in rare cases, with an incidence of 2.5%.[24] The cause of the hypoperfusion has been attributed to spasm,[25] flow capacity,[26] and technical problems, such as narrowing of IMA anastomoses, or kinking or stretching of the IMA grafts, or the superior epigastric or musculophrenic branch being used.[19] Calafiore et al.[24] stated the cause was a dysfunctioning left IMA damaged during harvest causing a spasm, subintimal hemorrhage or dissection with an abrupt fall of blood flow. If this syndrome is due to a composite graft, the myocardium it involves would be more than that of a single graft, and the risk would be much higher. The solution was immediate placement of a saphenous vein graft to the area of hypoperfusion.[19] Galbut and associates[27] reported a 15.4% rate of respiratory complications including pneumonia or significant atelectasis in patients undergoing bilateral IMA grafting. Using both IMAs increases the chance of phrenic nerve injury, which contributes to perioperative respiratory problems.

A prospective study showed the arterial graft patency of free right IMA at 5 years was 89%, while that of the left IMA was 96%.[20] Significance was found between the patency rates of pedicled IMA (96.3%) and of free anastomoses (86.5%).[17] Yamashiro and associates[28]

concluded that results obtained with free IMA were comparable to those obtained with pedicled IMA. However, the patency rate was lower if the right IMA was used as a free graft.[20,29] Arterial free conduits anastomosed to the ascending aorta had lower patency rates than did pedicled IMA grafts.[30] If they were placed as free grafts with proximal anastomoses on the ascending aorta, they would be exposed to a rate of rise of left ventricular pressure different from their native positions, as the modified wall stress could be the basis of early and late failure.[24] Graft patency was 97.3% in the bilateral IMA group and 94.3% in the single IMA group at a median follow-up of 6.15 years.[31]

No difference was noted between the overall patency rates of pedicled left (97%) versus right IMA (93%) out of the 1367 arterial anastomoses at a mean follow-up of 7.5 years.[17] The pedicled left or right IMA grafts when placed on the left system appear particularly satisfactory.[32] The patency rate of IMA grafts at 10 years after operation was 95%.[33] The patency rates at 17-year follow-up were 92.1% and 84.4% for the left and right IMAs, respectively,[34] and their overall patency rate was 88.9% at 20 years after operation.[35] Skeletonization of the IMA may increase its length and allow for sequential grafting and more distal anastomoses. But skeletonization is likely to get an intraluminal hematoma during harvest, and the handling during the anastomoses is more delicate. Nevertheless, it appears to have decreased the occurrence of sternal wound infections.[23] The patency rates of the skeletonized IMA were 97.1% and 99.6% for the left and right IMAs, respectively, at 2 to 3 weeks after the operation.[36] However, the effect of skeletonization of the IMA on its long-term patency has not been established. Sequential IMA anastomoses yield excellent patency rates to all coronary arteries but the very distal circumflex and the distal branches of the right coronary artery. Poor patency rate of anastomoses was noted as 80% when sequential free IMA were grafted to the ascending aorta. There was no significant difference between the patency rates of the sequential left and right IMA anastomoses (97% vs. 100%).[17] The patency rate of T-graft was considerably better than that for free graft anastomosed to the ascending aorta.[19]

The target artery has been recognized as an important determinant of IMA graft patency. The patency rates of both the left and right IMAs were excellent when anastomosed to the LAD.[37,38] Chow et al.[39] found that according to target vessels bypassed, the patency rates of the right and the left IMAs were similar. When in situ right IMA was anastomosed to the LAD, the results were similar to those of left IMA grafting. An increased risk of graft failure of the right IMA was markedly associated with grafting the low-grade stenosed or non-LAD coronary arteries.[40] The graft occlusion rate using free and, to a lesser extent, pedicled IMA grafts on the right side was high. The failure rate was 0.5%-1% per annum for the left IMA when grafted to the LAD. Competitive flow is an important factor influencing the patency of the graft.[40] Villareal and Mathur[41] analyzed IMA failure due to string phenomenon which was probably the competitive flow. The patency rates of the left IMA were similar to those of the right (96.7% vs. 96.3%) for the LAD, and for the circumflex (95.8% vs. 93.2%). The patency rate of the right IMA to the circumflex (via the transverse sinus) (93.2%) was as excellent as the right IMA to the LAD (96.3%), while to the distal right coronary artery it was lower (83%).[17]

There was no significant difference between patients of single and bilateral IMAs in the incidence of reoperation for bleeding (2.5% vs. 5%), sternal infection (2.5% vs. 2%), postoperative respiratory insufficiency (2% vs. 1%), myocardial infarction (5% vs. 3%), or stroke (1.5% vs. 0%). Durations of aortic crossclamp and cardiopulmonary bypass were slightly prolonged with the use of bilateral IMAs.[42] Fiore et al.[43] observed that the second mammary artery increased operative mortality. Sergeant et al.[44] bypassed the right IMA to the diagonal branch; they found the mortality was not significantly different from that of the single IMA group at 3.3-year follow-up. Berreklouw et al.[42] confirmed the hospital mortality was 0.9%-9% in bilateral IMA group, and was 0%-2.8% in the left IMA group, without any statistically significant differences. The 15-year actuarial survival rate was 70%. They noted that the bilateral IMAs with the second IMA bypassed to the right coronary artery could improve freedom of myocardial infarction and recurrent angina.[45]

Pedicled left IMA anastomosed to the LAD has been accepted as the standard coronary bypass style.[46] The right IMA is used frequently as a free graft because of its greater flexibility. Early postoperative coronary angiography demonstrated that when bilateral IMAs were required, the best choice of anastomosis was the right

IMA to the LAD, and the left IMA to the circumflex or diagonal coronary branches.[32] The use of the IMA in coronary bypass surgery increases longevity and lowers the incidence of early and late cardiac events.[12] Total revascularization by using the IMA could increase the long-term event-free survival, and reduce the need for reoperation in triple-vessel-diseased patients.[19]

The Radial Artery

The radial artery graft was first introduced into coronary surgery by Carpentier et al.[7] in the early 1970's. Their initial experience revealed that the radial artery was prone to spasm,[7] and to accelerated intimal hyperplasia.[47] Use of the radial artery as a bypass graft was condemned 20 years ago, but has been revived recently, with encouraging early results.[48]

The radial artery is of uniform size, valveless, and adapted to arterial pressure and flow. The lumen is 2 to 2.5 mm in diameter, and the mean length of the radial artery that was reported in the early years was 22 cm.[7] Recently, its usable length in CABG was reported to be 10 to 21 cm.[49-52] Conduit length, ease of handling, and concomitant harvesting are merits of the radial artery. The graft size is exactly adapted to the coronary artery; the elasticity of the arterial wall and the regularity of the lumen provide physiological flow.[7] It can be used in the distal target coronary vessel, or for multiple sequential anastomoses with different levels of occlusion.[24] The endothelial function of the radial artery is slightly inferior to that of the IMA.[53] There are more fenestrations in the internal elastic lamina than in the IMA.[54] The elastic laminae of the radial artery are monolayered with multiple fenestrations. That's why atherosclerotic change is more prevalent in the radial artery at the time of surgery.[55] About 1% to 5% of the harvested radial arteries were not used for bypass conduit due to the presence of marked atherosclerotic change.[56-58] Gaudino et al.[59] discovered that this atherosclerotic change in the radial artery had little impact on the mid-term graft patency rate. It has a thicker media layer, approximately 1.7-fold thicker than the IMA media, that makes it easier to spasm. Non-obstructive calcification was noted in three severely diabetic patients by Acar.[60]

The indication for the use of the radial artery is to supplement as an additional arterial graft to the IMA in young patients requiring total arterial revascularization.[61]

In patients having a redo procedure, the radial artery may have been catheterized and occasionally shows a fibrotic reaction in its distal segment. The proximal portion can be used as a graft.[60] The use of the radial artery is dependent on the result of the Allen test, which contraindicates the harvesting of this artery in about 5%-10% of patients, when it is the main supply of blood to the hand.[24] The radial artery may not be an appropriate conduit in patient of severe chronic renal failure likely to require hemodialysis through a radial arteriovenous fistula.[60]

Transient dysesthesia in the area of the skin incision and dorsum of the hand secondary to surgical trauma was noted in 5% (2/40) of patients. Transient paresthesia in the lateral thenar eminance occurred in one patient.[60] About 10% of patients experienced minor numbness at the base of the thumb.[61] The mean systolic blood pressure in the thumb was reduced by about 5% in patients who had a radial artery harvested.[32] Severe hand ischemia after radial artery harvest is an extremely rare complication, having been reported in only four patients.[62] The incidences of segmental narrowing and the string sign were 6% to 10%[48,63] and 3% to 5%,[48,56,63] respectively. Competitive flow reduces radial artery patency so that stenosis must be at least 70% and perhaps should be 80% to 90% for larger coronary arteries.[64] Spasm of the arterial graft occurred immediately after its removal in 25% of patients.[7] García-Rinaldi et al.[61] administered intravenous milrinone for 24 hours and oral diltiazem for one year in their patients using radial arterial grafts. Calafiore et al.[24] suggested calcium-channel blocker treatment last 4 weeks for arterial grafts when the radial artery was used.

Early graft patency studies of 35 radial artery grafts showed 33 (94%) were patent at a mean of 12 months.[32] Another early postoperative angiographic controls demonstrated 93.3% (14/15) patency of composite grafts with the IMA and radial artery.[65] Radial artery graft patency was approximately 85% at 5 years when the vessel was attached proximally to the ascending thoracic aorta and used as a single graft. This suggests that it would be better than a vein graft but not as good as a pedicled IMA graft.[66] Five-year data showed radial artery patency was inferior to that of the right IMA.[64] The 1-year graft patency rate of the skeletonized radial artery was 95.2%, and the anastomosis patency rate was 97.2%. Extensive

skeletonization did not affect the patency or spasm.[67] The patency rate of the radial artery was much affected by the severity of the target vessel stenosis, but was little affected by the target vessel location, whereas the right IMA patency rate was strongly affected by the target vessel location.[68]

Studies proved that the survival rate was similar between patients with a radial artery graft and those with a right IMA graft.[69,70] Caputo et al.[71] noted improved actuarial freedom from cardiac events in their radial artery group. Calafiore et al.[72] conducted a retrospective study in which the target was limited to the lateral wall and concluded that 8-year survival and cardiac event-free survival did not differ between patients with a radial artery and those with a right IMA graft.

The radial artery is of sufficient length to reach almost any target and has been used commonly to graft the circumflex, posterior descending and posterolateral branches. Bilateral radial artery grafting is particularly well tolerated in older patients, and in diabetic patients when used to supplement a single or bilateral IMA reconstruction. Radial artery grafting does not prolong aortic crossclamp time. Sequential radial artery grafting may reduce the time of the operation, and minimize the length of arterial conduits.[32] And suturing this graft is similar to using an IMA graft.[62]

The Right Gastroepiploic Artery

In 1975, Vineberg et al.[73] first proposed that the gastroepiploic artery could be used to revascularize acute myocardial infarctions. Black and Gibbons[74] first reported the angiographic result of using a gastroepiploic artery graft to the left circumflex coronary artery.

The usable length of the gastroepiploic artery was 12.8 cm.[5] Its internal diameter was 2.3 mm.[75] Histological studies revealed that its mean luminal diameter was 2.7 ± 0.3 mm at its origin, 2.2 ± 0.4 mm at 10 cm, and 1.8 ± 0.5 mm at 15 cm. It showed mild intimal hyperplasia at its origin, with a gradually decreasing degree of intimal hyperplasia along its course. Its media was muscular with rare dispersed elastic fibers.[76] Atherosclerotic plaques occurred in 24% of gastroepiploic arteries.[5] All gastroepiploic artery specimens had moderate to severe atherosclerotic changes with CD68-positive cell infiltration.[77] Only mild intimal hyperplasia was noted in the pedicled gastroepiploic artery-right coronary artery graft

at 19, 38 and 47 months after the operation.[76] No noticeable atheroslcerosis was found at 5-year angiography.[78]

The indication for using the gastroepiploic artery was unavailability of the IMAs or suitable veins or to avoid using vein grafts in young patients or in patients with diabetes mellitus.[77,79] It's preferable for LAD when the left IMA is unavailable in reoperation or in patients with large gastroepiploic artery but small IMAs.[79] Absolute contraindications were severe chronic obstructive airway disease, cardiogenic shock, extreme chest deformities, and severe or poorly controlled diabetes. Previous upper abdominal surgery was a relative contraindication. Cholecystectomy was not a contraindication.[80]

The right gastroepiploic artery was preferentially used as an in situ graft bypassing the right coronary artery and its distal branches. Sometimes, it was used as a free graft, mainly to bypass the diagonal or obtuse marginal branch. Suma et al.[79] proposed the suitability of the gastroepiploic artery as a conduit for the LAD. Sequential grafting was not done.[81]

One month after operation, 93%-97% of the gastroepiploic arteries were patent.[79,82] At 2-year follow-up, excellent patency of gastroepiploic artery-LAD graft was noted, without any signs of focal stenosis due to intimal hyperplasia.[73] The patency rate was greater than 90% at 3- to 4-year,[83] and was 82.1%-95% at 5-year follow-up.[69,75] The 3- and 5-year actuarial survival rates of patients receiving pedicled gastroepiploic artery to the right coronary artery were 95.8% and 91.6%, respectively, and the 1-, 3-, and 5-year patency rates were 95.7%, 90.2%, and 85.7%, respectively.[84] Suma and associates[85] reported a 10-year patency rate of 62.5%. Perioperative mortality was 3%, and late mortality was 2%. Angina was relieved in 98% of the patients.[81] Unadjusted actuarial survival rate at 5 years was 93% and at 10 years 87%. The actuarial 10-year survival was 91% by using bilateral IMAs and the right gastroepiploic artery.[80]

Long-term follow-up revealed that the right gastroepiploic artery grafts functioned better due to the further development of the coronary artery disease,[77] the same observation has been reported for IMA grafts.[75] The right gastroepiploic artery graft flow increases with meals, whereas IMA flow does not.[81] Incidence of postoperative sternal infection was as high as 9.7%. One patient developed a gastric ulcer 7 days postoperatively.

It was uncertain whether that was due to the disturbance of the blood supply to the gastric mucosa or postoperative stress.[78] Other complications included gastric bleeding at the lesser curvature, ventral hernia,[81] pancreas-derived hyperamylasemia and pancreatitis.[86]

Disadvantage of using the right gastroepiploic artery is the requirement of extending the sternal incision to the upper abdominal wall. Takedown of the right gastroepiploic artery graft is time-consuming in patients who had a previous laparotomy and in obese patients with thick adipose tissue.[81] Another disadvantage of using this artery as a bypass graft is possible reduced flow to gastroepiploic but to other hepatic artery branches.[62] Competitive flow should be avoided when using a pedicled gastroepiploic artery graft.[87] Spasm has been noted in free gastroepiploic artery graft.[88] The spasm is frequently triggered by mechanical stimulation such as catheter insertion at angiography or surgical manipulation. No evidence of myocardial ischemia or angina pectoris was caused by spontaneous right gastroepiploic artery graft spasm.

The Inferior Epigastric Artery

The inferior epigastric artery was first reported as a coronary bypass graft by Vincent et al.[89] in 1990. The inferior epigastric artery has a constant diameter only in the first 5-6 cm of its course; then it shows a progressive and sensible caliber reduction. When it has to be grafted to the ascending aorta, it must be harvested in all its length, from the groin to the umbilicus.[90] After preparation with dilute papaverine-Plasmalyte solution, proximal sizes of the inferior epigastric artery ranged from 2.5 to 3.25 mm, and distal sizes measured 1.5 to 2.5 mm. The lengths of the conduit ranged from 11.5 to 17.0 cm.[91] A histological study revealed the mean luminal diameter of the inferior epigastric artery was 2.0 ± 0.4 mm at its origin, 1.9 ± 0.5 mm at 10 cm, and 1.1 ± 0.5 mm at 15 cm. There was substantial intimal hyperplasia in the inferior epigastric artery. The media of the inferior epigastric artery was muscular with rare dispersed elastic fibers.[63] It is characteristic of the smaller luminal diameter, reduced wall thickness, and muscular characteristics of the media.[58] Atherosclerosis was minimal in distal inferior epigastric artery.[92] Atherosclerotic plaques were noted in 28% of the inferior epigastric arteries.[5] The inferior epigastric artery seldom displays intimal thickening, and

has well-developed internal elastic lamina, and tunica media poor in elastic fibers while rich in smooth muscle cells.[93]

Size-matching of the graft to the coronary artery was appropriate.[94] The inferior epigastric artery was easily harvested.[95] The inferior epigastric artery grafts could be bypassed distally to any coronary arteries including the LAD. It could be used as sequential grafts or a natural Y-graft,[95] or branches or extensions of a pedicled IMA, thereby avoiding a proximal anastomosis on the ascending aorta.[90] Exposure of muscular inferior epigastric artery to the high sheer stress of the aorta may lead to accelerated development of intimal hyperplasia. To avoid this problem, the proximal inferior epigastric artery should be anastomosed to the aorta by way of a hood of saphenous vein or to an IMA graft.[76] An angiographic study at 6 months showed 17 of 19 inferior epigastric artery grafts and distal anastomoses remained patent. Microscopic examination of distal specimens of IMA and inferior epigastric artery harvested from the same patients showed a comparable continuous internal elastic lamina with only few disruptions in both arteries.[95]

The indications for using the inferior epigastric were absent or poor-quality vein, young age with an attempt to limit vein graft, and avoidance of use of bilateral internal mammary artery grafts in diabetic patients.[91] The inferior epigastric artery was not used if there had been a previous hernioplasty, if a surgical scar crossed the area of harvesting, or if the patient was obese. Age of 70 years or greater and a left ventricular ejection fraction of 0.35 or less were not a contraindication.[24]

Immediate patency was dramatically different. It was 57% when the inferior epigastric artery was used as a free graft,[96] and was 77.8%-89.5% for inferior epigastric-left IMA Y-grafts,[97,98] when grafting to other than the LAD. At one month postoperatively, 89.5% of the inferior epigastric artery grafts were patent.[95] The patency rate was 72% (13/18) at 3 months,[99] 79% at 14.8 months,[100] and 52.2% (12/23) at 21.2 months[96] after the operation. The postoperative angiography performed at 1.3 years or 2 years showed excellent inferior epigastric graft patency.[97] At 25 months, 86.2% (25/29) of the grafts were open.[100] Low patency rates were observed when the inferior epigastric artery was used on diagonal and obtuse marginal branches.[96] By relating the patency to the grafted coronary branch, it was 100% for the LAD

(3/3), and 40% (4/10) and 37.5% (3/8) for diagonal and obtuse marginal branches, respectively.[96]

Noting the poor early patency of inferior epigastric artery, Teerenhovi et al.[99] raised doubts concerning the vessel's suitability for myocardial revascularization. The early attrition rate of the inferior epigastric artery, as for any free arterial graft, may probably be the result of both the loss of a true pedicle and the need for constructing an additional proximal anastomosis. That the patency rate of the inferior epigastric artery graft seemed to remain stable beyond one year could suggest good durability.[100] Although hypoperfusion poses a serious problem in this technique, the inferior epigastric arteries may be considered to serve as an alternative for an arterial conduit.[101] Because of the low patency rate of the inferior epigastric graft, Y-graft using the inferior epigastric artery appears to be an interesting alternative.[102] The inferior epigastric elongation of the left IMA is another strategy to reach a lateral LAD in selected cases.[103]

The Subscapular Artery and its Branches

The subscapular artery together with its branches was first used as a free graft in three patients for coronary bypass by Mills and associates in 1992.[104]

The subscapular artery is the most distal and largest branch of the axillary artery. It emerges from the last third of the auxiliary and descends posteriorly and inferiorly. The thoracodorsal artery is the continuation of the subscapular artery in 75%, and a direct branch from the auxiliary artery in 25% of subjects. Lopata et al.[104] depicted the anatomic characteristics of this artery. The subscapular artery occurs in 88% of cases. Its average length is 2.4 cm, and its diameter is 4.6 mm. The thoracodorsal artery, i.e., the continuation of the subscapular artery, extends 4.8 to 12.8 cm long, and its diameter is 2.2 to 4.1 mm at its beginning and 1.0 to 2.4 mm at its terminal. Atherosclerotic changes were found at the opening of the subscapular artery in 12%, and in the artery itself in 4% of the examined cases.

Šimif et al.[105] reported one case of a free thoracodorsal graft 14 cm long and 2.5 mm in diameter, bypassed to the LAD. They anticipated that the thoracodorsal artery together with the circumflex scapular artery could be used as a natural Y-graft for the LAD and the first diagonal branch.

Watanabe et al.[106] reported one case of an in situ left thoracodorsal graft 8 cm long and 2.5 mm in diameter elongated with the radial artery bypassed to the obtuse marginal branch under MIDCAB. They concluded that MIDCAB with the thoracodorsal artery was suitable for patients with isolated left main disease or multivessel disease involving the LAD and circumflex systems. Yaginuma et al.[107] reported the use of the thoracodorsal artery in 3 cases, grafting to the obtuse marginal branch, to the left circumflex, right posterolateral, and right posterior descending arteries sequentially with a radial-thoracodorsal artery composite conduit, and to the obtuse marginal and diagonal branches with a thoracodorsal artery-left IMA Y-graft, respectively. All showed good results.

The Splenic Artery

The splenic artery as a coronary bypass graft has undergone a waning course. The usable length of the splenic artery is about 15 cm. There is good size approximation between the splenic and right coronary artery.[6] In 1973, Edwards and associates[6,108] employed the splenic artery by removing the spleen and freeing the artery back to the celiac axis. The splenic artery was then brought through the diaphragm and sutured to the distal right coronary artery as an in situ graft passing through the membranous portion of the diaphragm. Two postoperative splenic artery angiograms demonstrated widely patent anastomoses. Green[7] adopted Edwards' procedure of bringing the splenic artery up through the diaphragm to the right coronary artery as a satisfactory pedicled graft. Later, Edwards did not use the splenic artery any longer due to the difficulty of dissecting it.[48] Afterwards, Mueller et al.[109] reported one case of a free splenic artery grafted to the LAD with an excellent result.

The disadvantage of the splenic artery is its tortuous course as well as its large diameter as compared with the right coronary artery. But the tortuosity can be straightened when it is used as a free graft. The splenic artery should be mobilized behind the pancreas at the junction of the body and the tail with obligatory splenectomy. Meticulous dissection should be performed at the upper surface of the pancreas to avoid any injury to this organ.[109] Two splenic infarcts once occurred when the spleen was preserved, due to the splenic artery harvest.[108]

An interesting discovery of Edwards showed that the IMA and splenic artery remained patent connecting to their parent arteries, while the radial arteries, when used

as free grafts, failed. Late study illustrated that the patency rate of the splenic graft was about 90%.[48]

The Ulnar Artery

The ulnar artery lies next to the ulnar nerve, which carries important motor fibers supplying the small muscles of the hand. Its usable length is 15 cm, with a diameter of 2 to 3 mm. There is a reciprocal relationship between the size of the ulnar artery and the radial artery. Normally, the ulnar artery is the larger artery of the two forearms and the major source of blood for the hand. In a few of patients, the radial artery is the dominant artery. The ulnar artery can be either congenitally small, injured, or diseased. Severe calcification and atherosclerotic occlusion were each found in 10% of patients.[110] Like the radial artery, the ulnar artery, having a thick muscular media, may be prone to spasm.

The indication for the use of the ulnar artery is that the radial artery cannot be removed safely and the saphenous veins are unavailable or of poor quality. In patients in whom there is a different arterial pattern on each arm, the ulnar artery can be removed at the same time as the radial artery is harvested from the other arm.[110]

Careful dissection is required to avoid handling the nerve or exerting excessive traction. The length of the ulnar artery removed from the flexor compartment is usually less than that of the radial artery. Buxton et al.[110] reported that ten ulnar arteries removed for use as coronary artery bypass grafts, were anastomosed successfully to the diagonal and the right coronary arteries other than the LAD distally and directly to the aorta proximally, but without angiography.[110] Nie and associates[111] reported left ulnar artery grafting to the diagonal branch in one patient. The ulnar artery has been used as a single graft, but it is anticipated to be used as a sequential or T-graft in the same way as the radial artery.

One patient complained of pain and hand weakness in the distribution of the ulnar artery. No early hand or cardiac complications were observed after surgery.[110,111]

The Lateral Costal Artery

The lateral costal artery occurs in 27.6% of cadavers, either unilaterally or bilaterally.[112] When unilaterally, the left-sided is more common. If bilaterally, the length is not necessarily the same. The lateral costal artery arises from the IMA, and sometimes from the subclavian or supreme intercostal arteries. Slightly less than half of the lateral costal arteries reach the fifth or sixth intercostal space. Only a third ended at the first or second intercostal space. Therefore, 10%-15% of patients are likely to have a lateral costal artery suitable for coronary bypass. Its outer diameter is 2 mm and the total length is 20 cm.[112] In 1990, Hartmen et al.[112] reported their unique case of a free right lateral costal arterial graft successfully attached to in situ right IMA proximally, bypassed to the diagonal branch. Histological examination of the distal end showed no difference from IMA. They advocated its use in a large number of patients.

Other Arteries

A research was done on the potential suitability of the intercostal artery as a coronary bypass graft, which showed that the flows measured in the transected intercostal artery were 80-100 mL/min. Advantageous properties are multiple elastic lamellae in the media, a thin intima with low incidence of atherosclerosis and a thin media, and its close proximity to the heart. The potential disadvantages may consist of difficulty in harvesting due to the interference with the lungs and the curvature of the chest wall and the use only as a free graft. But there are no reports of its use as a coronary bypass graft.[113]

The left gastric and the gastroduodenal arteries were explored for the possibility of the arterial grafts instead of the splenic, but they are too small and too short.[108] This tentative idea is fading away.

SUMMARY

Relation exists between the contractility of an arterial conduit, which is usually proportional to the content of smooth muscle cells in its media, and its long-term patency. The arterial grafts currently used are second (the IMA), third (the radial artery, the inferior epigastric artery), and fourth (the right gastroepiploic artery) aortic branches. The IMA is elastic, but the others are muscular.

According to the literature, the primary choice of the arterial graft for coronary bypass is the left IMA, the second choice is the right IMA, the right gastroepiploic artery or radial artery, depending on the target anastomotic site and the degree of stenosis is the third, and

inferior epigastric artery is the fourth choice. The thoracodorsal, ulnar, splenic and lateral costal arteries should only be used as additional grafts.

In clinical practice in our department, we take the left IMA as the first choice of the arterial graft for coronary bypass, the right IMA, the second, and the left radial artery, the third. We do not use the right radial or double radial arteries. Nor do we use any other arteries. We appreciate other authors who have discovered various autologous arteries as additional alternatives and benefited us with their valuable experience. However, we have not had any chance to make an attempt to use additional arterial grafts. We only perform total arterial revascularization in patients younger than 70 years old free of diabetes, chronic renal failure or other critical diseases. It would be sufficient for total arterial revascularization with the use of bilateral IMAs and the left radial artery by way of sequential and T- or Y-graft configurations.

In conclusion, the left and right IMAs and radial artery are the first three choices in the graft selection for coronary bypass. Other arteries, such as the right gastroepiploic, inferior epigastric, thoracodorsal, ulnar, splenic and lateral costal arteries could be additional grafts based on the substantial circumstances of the patient.

REFERENCES

1. Goetz RH, Rohman M, Haller JD, et al. Internal mammary-coronary artery anastomoses: a nonsuture method employing tantalum rings. *J Thorac Cardiovasc Surg* 1961;41:378-86.

2. Kolessov VI. Mammary artery-coronary artery anastomosis as method of treatment for angina pectoris. *J Thorac Cardiovasc Surg* 1967;54:535-44.

3. Green GE. Technique of internal mammary-coronary artery anastomosis. *J Thorac Cardiovasc Surg* 1979;78:455-9.

4. Suzuki A, Kay EB, Hardy JD. Direct anastomosis of the bilateral internal mammary artery to the distal coronary artery, without a magnifier, for severe diffuse coronary atherosclerosis. *Circulation* 1973;48(1 Suppl):III190-7.

5. Wandschneider W, Wurnig P, Redtenbacher S, Deutsch M. Arterial grafts for coronary artery surgery. *Cardiovasc Surg* 1995; 3:525-7.

6. Edwards WS, Lewis CE, Blakeley WR, Napolitano L. Coronary artery bypass with internal mammary and splenic artery grafts. *Ann Thorac Surg* 1973;15:35-40.

7. 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.

8. Kay HR, Korns ME, Flemma RJ, et al. Atherosclerosis of the internal mammary artery. *Ann Thorac Surg* 1976;21:504-7.

9. Friedl R, Li J, Schumacher B, et al. Intimal hyperplasia and expression of transforming growth factor-β_1 in saphenous veins and internal mammary arteries before coronary artery surgery. *Ann Thorac Surg* 2004;78:1312-8.

10. Kroncke GM, Kosolcharoen P, Clayman JA, et al. Five-year changes in coronary arteries of medical and surgical patients of the Veterans Administration Randomized Study of Bypass Surgery. *Circulation* 1988;78(3 Pt 2):I144-50.

11. Del Campo C. Pedicled or skeletonized? A review of the internal thoracic artery graft. *Tex Heart Inst J* 2003;30:170-5.

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

13. Cosgrove DM, Loop FD, Lytle BW, et al. Does mammary artery grafting increase surgical risk? *Circulation* 1985;72(3 Pt 2): II170-4.

14. Gardner TJ, Greene PS, Rykiel MF, et al. Routine use of the left internal mammary artery graft in the elderly. *Ann Thorac Surg* 1990;49:188-93.

15. Pick AW, Orszulak TA, Anderson BJ, Schaff HV. Single versus bilateral internal mammary artery grafts: 10-year outcome analysis. *Ann Thorac Surg* 1997;64:599-605.

16. Bical OM, Khoury W, Fromes Y, et al. Routine use of bilateral skeletonized internal thoracic artery grafts in middle-aged diabetic patients. *Ann Thorac Surg* 2004;78:2050-3.

17. Dion R, Glineur D, Derouck D, et al. Long-term clinical and angiographic follow-up of sequential internal thoracic artery grafting. *Eur J Cardiothorac Surg* 2000;17:407-14.

18. Accola KD, Jones EL, Craver JM, et al. Bilateral mammary artery grafting: avoidance of complications with extended use. *Ann Thorac Surg* 1993;56:872-8; discussion 878-9.

19. Tector AJ, Amundsen S, Schmahl TM, et al. Total revascularization with T grafts. *Ann Thorac Surg* 1994;57:33-8; discussion 39.

20. Tatoulis J, Buxton BF, Fuller JA. Results of 1,454 free right internal thoracic artery-to-coronary artery grafts. *Ann Thorac Surg* 1997;64:1263-8.

21. Puig LB, França Neto L, Rati M, et al. A technique of anastomosis of the right internal mammary artery to the circumflex artery and its branches. *Ann Thorac Surg* 1984;38:533-4.

22. Kouchoukos NT, Wareing TH, Murphy SF, et al. Risks of bilateral internal mammary artery bypass grafting. *Ann Thorac Surg* 1990;49:210-7.

23. Matsa M, Paz Y, Gurevitch J, et al. Bilateral skeletonized internal thoracic artery grafts in patients with diabetes mellitus. *J Thorac Cardiovasc Surg* 2001;121:668-74.

24. Calafiore AM, Di Giammarco G, Teodori G, et al. Radial artery and inferior epigastric artery in composite grafts: improved midterm angiographic results. *Ann Thorac Surg* 1995;60:517-23.

25. Sarabu MR, McClung JA, Fass A, Reed GE. Early postoperative spasm in left internal mammary artery bypass grafts. *Ann Thorac*

Surg 1987;44:199-200.

26. Jones EL, Lattouf OM, Weintraub WS. Catastrophic consequences of internal mammary artery hypoperfusion. *J Thorac Cardiovasc Surg* 1989;98(5 Pt 2):902-7.

27. Galbut DL, Traad EA, Dorman MJ, et al. Twelve-year experience with bilateral internal mammary artery grafts. *Ann Thorac Surg* 1985;40:264-70.

28. Yamashiro S, Sakata R, Nakayama Y, et al. Long-term angiographic evaluation of free internal thoracic artery grafting for myocardial revascularization. *Ann Thorac Cardiovasc Surg* 2000;6:378-82.

29. Verhelst R, Etienne PY, El Khoury G, et al. Free internal mammary artery graft in myocardial revascularization. *Cardiovasc Surg* 1996;4:212-6.

30. Schimert G, Vidne BA, Lee AB Jr. Free internal mammary artery graft: an improved surgical technique. *Ann Thorac Surg* 1975; 19:474-7.

31. Endo M, Nishida H, Tomizawa Y, Kasanuki H. Benefit of bilateral over single internal mammary artery grafts for multiple coronary artery bypass grafting. *Circulation* 2001;104:2164-70.

32. Buxton BF, Fuller JA, Tatoulis J. Evolution of complete arterial grafting: for coronary artery disease. *Tex Heart Inst J* 1998; 25:17-23.

33. Grondin CM, Campeau L, Lesperance J, et al. Comparison of late changes in internal mammary artery and saphenous vein grafts in two consecutive series of patients 10 years after operation. *Circulation* 1984;70(3 Pt 2):I208-12.

34. Galbut DL, Traad EA, Dorman MJ, et al. Seventeen-year experience with bilateral internal mammary artery grafts. *Ann Thorac Surg* 1990;49:195-201.

35. Voutilainen SM, Järvinen AA, Verkkala KA, et al. Angiographic 20-year follow-up of 61 consecutive patients with internal thoracic artery grafts. *Ann Surg* 1999;229:154-8.

36. Nishida H, Tomizawa Y, Endo M, et al. Coronary artery bypass with only in situ bilateral internal thoracic arteries and right gastroepiploic artery. *Circulation* 2001;104(12 Suppl 1):I76-80.

37. Rankin JS, Newman GE, Bashore TM, et al. Clinical and angiographic assessment of complex mammary artery bypass grafting. *J Thorac Cardiovasc Surg* 1986;92:832-46.

38. Nishida H, Tagusari O, Yamaki F, et al. A right internal thoracic artery graft to the left anterior descending artery. *Kyobu Geka* 1993;46:206-9.

39. Chow MS, Sim E, Orszulak TA, Schaff HV. Patency of internal thoracic artery grafts: comparison of right versus left and importance of vessel grafted. *Circulation* 1994;90(5 Pt 2):II129-32.

40. Buxton BF, Ruengsakulrach P, Fuller J, et al. The right internal thoracic artery graft — benefits of grafting the left coronary system and native vessels with a high grade stenosis. *Eur J Cardiothorac Surg* 2000;18:255-61.

41. Villareal RP, Mathur VS. The string phenomenon: an important cause of internal mammary artery graft failure. *Tex Heart Inst J* 2000;27:346-9.

42. Berreklouw E, Schönberger JP, Bavinck JH, et al. Similar hospital

morbidity with the use of one or two internal thoracic arteries. *Ann Thorac Surg* 1994;57:1564-72.

43. Fiore AC, Naunheim KS, Dean P, et al. Results of internal thoracic artery grafting over 15 years: single versus double grafts. *Ann Thorac Surg* 1990;49:202-8.

44. Sergeant P, Lesaffre E, Flameng W, Suy R. Internal mammary artery: methods of use and their effect on survival after coronary bypass surgery. *Eur J Cardiothorac Surg* 1990;4:72-8.

45. Fiore AC, Naunheim KS, McBride LR, et al. Fifteen-year follow-up for double internal mammary artery grafts. *Eur J Cardiothorac Surg* 1991;5:248-52.

46. Mack MJ, Osborne JA, Shennib H. Arterial graft patency in coronary artery bypass grafting: what do we really know? *Ann Thorac Surg* 1998;66:1055-9.

47. Curtis JJ, Stoney WS, Alford WC Jr, et al. Intimal hyperplasia: a cause of radial artery aortocoronary bypass graft failure. *Ann Thorac Surg* 1975;20:628-35.

48. Acar C, Jebara VA, Portoghese M, et al. Revival of the radial artery for coronary artery bypass grafting. *Ann Thorac Surg* 1992;54:652-9.

49. Buklas D, Gelpi G, Neri E, et al. Less invasive radial artery harvesting: two years' experience. *Heart Surg Forum* 2005;8: E437-42.

50. Yoshizaki T, Arai H, Igari T, et al. Endoscopic radial artery harvesting: our initial experience and results of the first 25 patients. *Ann Thorac Cardiovasc Surg* 2005;11:391-6.

51. Roskoph K, Navid F, Jubeck M, et al. A safe and cost-effective approach to minimally invasive radial artery harvesting. *Ann Thorac Surg* 2005;80:700-3.

52. Chiu KM, Li SJ, Chen JS, et al. Endoscopic radial artery harvest for coronary artery bypass surgery. *J Formos Med Assoc* 2006; 105:384-9.

53. He GW. Nitric oxide and endothelium-derived hyperpolarizing factor in human arteries and veins. *J Card Surg* 2002;17:317-23.

54. van Son JA, Smedts F, Vincent JG, et al. Comparative anatomic studies of various arterial conduits for myocardial revascularization. *J Thorac Cardiovasc Surg* 1990;99:703-7.

55. Kaufer E, Factor SM, Frame R, Brodman RF. Pathology of the radial and internal thoracic arteries used as coronary artery bypass grafts. *Ann Thorac Surg* 1997;63:1118-22.

56. Amano A, Hirose H, Takahashi A, Nagano N. Coronary artery bypass grafting using the radial artery: midterm results in a Japanese institute. *Ann Thorac Surg* 2001;72:120-5.

57. Wendler O, Hennen B, Demertzis S, et al. Complete arterial revascularization in multivessel coronary artery disease with 2 conduits (skeletonized grafts and T grafts). *Circulation* 2000; 102(19 Suppl 3):III79-83.

58. Weinschelbaum EE, Macchia A, Caramutti VM, et al. Myocardial revascularization with radial and mammary arteries: initial and mid-term results. *Ann Thorac Surg* 2000;70:1378-83.

59. Gaudino M, Tondi P, Serricchio M, et al. Atherosclerotic involvement of the radial artery in patients with coronary artery disease and its relation with midterm radial artery graft patency

and endothelial function. *J Thorac Cardiovasc Surg* 2003;126: 1968-71.

60. Reyes AT, Frame R, Brodman RF. Technique for harvesting the radial artery as a coronary artery bypass graft. *Ann Thorac Surg* 1995;59:118-26.

61. García-Rinaldi R, Soltero ER, Carballido J, Mojica J. Intraluminal milrinone for dilation of the radial artery graft. *Tex Heart Inst J* 1999;26:189-91.

62. Manabe S, Sunamori M. Radial artery graft for coronary artery bypass surgery: biological characteristics and clinical outcome. *J Card Surg* 2006;21:102-14.

63. da Costa FD, 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.

64. Barner HB. Status of the radial artery: where does it fit? *J Card Surg* 2006;21:115.

65. Watanabe G, Ueyama K, Misaki T, et al. Composite arterial conduits with internal thoracic artery and radial artery for a myocardial revascularization. *Kyobu Geka* 1997;50:912-17.

66. Acar C, Ramsheyi A, Pagny JY, et al. The radial artery for coronary artery bypass grafting: clinical and angiographic results at five years. *J Thorac Cardiovasc Surg* 1998;116:981-9.

67. Hirose H, Amano A. Skeletonized radial artery grafting: one-year patency rate. *Heart Surg Forum* 2004;7:E277-82.

68. Tatoulis J, Buxton BF, Fuller JA. Patencies of 2127 arterial to coronary conduits over 15 years. *Ann Thorac Surg* 2004;77: 93-101.

69. Buxton BF, Raman JS, Ruengsakulrach P, et al. Radial artery patency and clinical outcomes: five-year interim results of a randomized trial. *J Thorac Cardiovasc Surg* 2003;125:1363-71.

70. Lemma M, Gelpi G, Mangini A, et al. Myocardial revascularization with multiple arterial grafts: comparison between the radial artery and the right internal thoracic artery. *Ann Thorac Surg* 2001;71:1969-73.

71. Caputo M, Reeves B, Marchetto G, et al. Radial versus right internal thoracic artery as a second arterial conduit for coronary surgery: early and midterm outcomes. *J Thorac Cardiovasc Surg* 2003;126:39-47.

72. Calafiore AM, Di Mauro M, D'Alessandro S, et al. Revascularization of the lateral wall: long-term angiographic and clinical results of radial artery versus right internal thoracic artery grafting. *J Thorac Cardiovasc Surg* 2002;123:225-31.

73. Vineberg A, Afridi S, Sahi S. Direct revascularization of acute myocardial infarction by implantation of left internal mammary artery into infarcted left ventricular myocardium. *Surg Gynecol Obstet* 1975;140:44-52.

74. Black AJ, Gibbons F. Angiographic visualization of a right gastroepiploic artery-left circumflex coronary artery graft. *Cathet Cardiovasc Diagn* 1987;13:121-4.

75. Reddy DB, Das B, Dogra TD, Venugopal P. Dimensions of potential arterial grafts for coronary artery bypass grafting in Indians: an autopsy evaluation study. *Indian Heart J* 1991;43: 101-4.

76. van Son JA, Smedts FM, Yang CQ, et al. Morphometric study of the right gastroepiploic and inferior epigastric arteries. *Ann Thorac Surg* 1997;63:709-15.

77. Tomizawa Y, Endo M, Nishida H, et al. Use of arterial grafts for coronary revascularization: experience of 2987 anastomoses. *Jpn J Thorac Cardiovasc Surg* 1999;47:325-9.

78. Voutilainen S, Verkkala K, Järvinen A, Keto P. Angiographic 5-year follow-up study of right gastroepiploic artery grafts. *Ann Thorac Surg* 1996;62:501-5.

79. Suma H, Amano A, Fukuda S, et al. Gastroepiploic artery graft for anterior descending coronary artery bypass. *Ann Thorac Surg* 1994;57:925-7.

80. Tavilla G, Kappetein AP, Braun J, et al. Long-term follow-up of coronary artery bypass grafting in three-vessel disease using exclusively pedicled bilateral internal thoracic and right gastroepiploic arteries. *Ann Thorac Surg* 2004;77:794-9.

81. Suma H, Wanibuchi Y, Terada Y, et al. The right gastroepiploic artery graft: clinical and angiographic midterm results in 200 patients. *J Thorac Cardiovasc Surg* 1993;105:615-22.

82. Nishida H, Sato M, Uwabe K, et al. Coronary artery bypass grafting with both internal thoracic arteries and the right gastroepiploic artery. *J Cardiovasc Surg (Torino)* 1996;37:471-4.

83. Spence PA, Gray LA Jr. New conduits for coronary artery bypass: great promise for improved outcome from coronary artery surgery. *J Ky Med Assoc* 1994;92:52-8.

84. Hirose H, Amano A, Takahashi A. Bypass to the distal right coronary artery using in situ gastroepiploic artery. *J Card Surg* 2004;19:499-504.

85. Suma H, Isomura T, Horii T, Sato T. Late angiographic result of using the right gastroepiploic artery as a graft. *J Thorac Cardiovasc Surg* 2000;120:496-8.

86. Lytle BW, Cosgrove DM, Ratliff NB, Loop FD. Coronary artery bypass grafting with the right gastroepiploic artery. *J Thorac Cardiovasc Surg* 1989;97:826-31.

87. Mills NL, Hockmuth DR, Everson CT, Robart CC. Right gastroepiploic artery used for coronary artery bypass grafting: evaluation of flow characteristics and size. *J Thorac Cardiovasc Surg* 1993;106:579-85.

88. Attum AA. The use of the gastroepiploic artery for coronary artery bypass graft: another alternative. *Tex Heart Inst J* 1987; 14:289-92.

89. Vincent JG, van Son JA, Skotnicki SH. Inferior epigastric artery as a conduit in myocardial revascularization: the alternative free arterial graft. *Ann Thorac Surg* 1990;49:323-5.

90. Calafiore AM, Di Giammarco G, Luciani N, et al. Composite arterial conduits for a wider arterial myocardial revascularization. *Ann Thorac Surg* 1994;58:185-90.

91. Mills NL, Everson CT. Technique for use of the inferior epigastric artery as a coronary bypass graft. *Ann Thorac Surg* 1991;51: 208-14.

92. Teerenhovi O, Aine R, Pekhonen E, Tarkka M. Atherosclerosis of the inferior epigastric and internal mammary arteries. *Scand J Thorac Cardiovasc Surg* 1995;29:59-61.

131

93. Hayashi S, Kawaue Y. Experience of coronary artery bypass grafting with inferior epigastric artery (IEA) and pathological examination of the IEA. *Nippon Kyobu Geka Gakkai Zasshi* 1995;43:43-6.

94. Sato T, Isomura T, Hisatomi K, et al. Use of inferior epigastric artery for coronary artery bypass grafting. *Kyobu Geka* 1995; 48:1025-9.

95. Buche M, Schoevaerdts JC, Louagie Y, et al. Use of the inferior epigastric artery for coronary bypass. *J Thorac Cardiovasc Surg* 1992;103:665-70.

96. Donatelli F, Triggiani M, Benussi S, D'Ancona G. Inferior epigastric artery as a conduit for myocardial revascularization: a two-year clinical and angiographic follow-up. *Cardiovasc Surg* 1998;6:520-4.

97. Fukuda S, Suma H, Ikeda S, et al. The inferior epigastric artery as a coronary artery bypass graft. *Kyobu Geka* 1995;48:1096-100.

98. Perrault LP, Carrier M, Hébert Y, et al. Early experience with the inferior epigastric artery in coronary artery bypass grafting: a word of caution. *J Thorac Cardiovasc Surg* 1993;106:928-30.

99. Teerenhovi O, Pehkonen E, Tarkka M, et al. Inferior epigastric artery as a conduit for myocardial revascularization. *Scand J Thorac Cardiovasc Surg* 1994;28:1-4.

100. Buche M, Schroeder E, Gurne O, et al. Coronary artery bypass grafting with the inferior epigastric artery: midterm clinical and angiographic results. *J Thorac Cardiovasc Surg* 1995;109:553-9.

101. Kawaue Y, Uchida N. Y-grafting using the inferior epigastric artery for coronary revascularization. *Nippon Kyobu Geka Gakkai Zasshi* 1995;43:1701-5.

102. Takahashi K, Odagiri S, Nagao K. CABG using Y arterial graft which consists of internal thoracic artery Y branched with inferior epigastric artery. *Kyobu Geka* 1995;48:1030-3.

103. Calafiore AM, Teodori G, Di Giammarco G, et al. Left internal mammary elongation with inferior epigastric artery in minimally invasive coronary surgery. *Eur J Cardiothorac Surg* 1997;12: 393-6.

104. Lopata P, Mikusek J, Zembala M, Jedrzejczyk T. Subscapular artery as a material for aorto-coronary bypass graft. *Folia Morphol (Warsz)* 1996;55:382-3.

105. Šimiƒ O, Zambelli M, Zeliƒ M, Pirjavec A. Thoracodorsal artery as a free graft for coronary artery bypass grafting. *Eur J Cardiothorac Surg* 1999;16:94-6.

106. Watanabe G, Misaki T, Kotoh K, Ueyama K. Left thoracodorsal artery as an inflow graft for minimally invasive direct coronary artery bypass grafting. *J Thorac Cardiovasc Surg* 1998;116: 524-5.

107. Yaginuma G, Sakurai M, Meguro T, Ota K. Thoracodorsal artery as a free arterial graft for myocardial revascularization. *Ann Thorac Surg* 2001;72:915-6.

108. Edwards WS, Blakeley WR, Lewis CE. Technique of coronary bypass with autogenous arteries. *J Thorac Cardiovasc Surg* 1973; 65:272-5.

109. Mueller DK, Blakeman BP, Pickleman J. Free splenic artery used in aortocoronary bypass. *Ann Thorac Surg* 1993;55:162-3.

110. Buxton BF, Chan AT, Dixit AS, et al. Ulnar artery as a coronary bypass graft. *Ann Thorac Surg* 1998;65:1020-4.

111. Nie M, Ohara K, Miyoshi Y, et al. Ulnar artery graft for myocardial revascularization. *Jpn J Thorac Cardiovasc Surg* 2000; 48:112-4.

112. Hartman AR, Mawulawde KI, Dervan JP, Anagnostopoulos CE. Myocardial revascularization with the lateral costal artery. *Ann Thorac Surg* 1990;49:816-8.

113. van Son JA, Smedts F, Korving J, et al. Intercostal artery: histomorphometric study to assess its suitability as a coronary bypass graft. *Ann Thorac Surg* 1993;56:1078-81.

冠狀動脈繞道手術中自體動脈性繞道血管的選擇

袁師敏　　欣菲爾德•阿米海　卡哈勒•埃萊茲　拉納尼•烏迪

以色列　特拉肖邁爾　海姆・謝巴醫療中心　心胸外科

本文透過 MEDLINE 資訊收集，將針對冠狀動脈繞道手術中自體動脈性繞道血管作全面概括的探討。搜尋主題包括動脈性繞道血管和冠狀動脈繞道手術。對於常用的動脈性繞道血管，包括內乳動脈 (IMA)、橈動脈、右胃網膜動脈和腹壁下動脈，相關文章進行選取並顯示形態學特徵、與通暢率上的差異並比較其優缺點。對於少數零星病案報導的動脈性繞道血管，例如肩胛下動脈、尺動脈、脾動脈和側肋動脈也進行廣泛收集。

搜尋結果發現：左右雙側 pedicled 內乳動脈有相似的通暢率。Pedicled 內乳動脈比游離的內乳動脈繞道血管有較高的通暢率。然而胸骨感染的發生與患者使用雙側內乳動脈有關。Skeletonized 內乳動脈雖提供更好的胸骨灌注，但會造成局部血管壁傷害。繞道吻合於低度狹窄或非左前降支的冠狀動脈將增加內乳動脈繞道血管失敗的風險。內乳動脈比其他動脈性繞道血管的通暢率上的優勢可歸結於它優越的內皮細胞作用及血流重建。內乳動脈屬於彈力性的血管，而其他是肌性的血管。而內乳動脈的 20 年的通暢率為 88.9%，橈動脈的 5 年的通暢率為 85%，右胃網膜動脈的 5 年的通暢率為 85.7%，腹壁下動脈在術後 21.2 月的通暢率為 52.2%。其他的動脈性繞道血管亦有少許報告，並顯示良好的結果。

所以冠狀動脈繞道手術中自體動脈性繞道血管的選擇，首選是左側 IMA，其次為右側 IMA，橈動脈則為第三優先選擇。而其他動脈亦可作為替代選擇。

關鍵詞： 動脈性繞道血管、冠狀動脈繞道手術、通暢率。