Senior Cardiovascular Surgical Society

The Development of Coronary Artery Surgery

Personal Recollections

John E. Connolly, MD

About a month before graduation from Harvard Medical School, I had the opportunity to attend the 1948 meeting of the American Surgical Association in Quebec. At that meeting, Claude Beck of Cleveland reported the 1st creation, in a human being, of an arteriovenous fistula between the aorta and the coronary sinus by the use of a free brachial artery graft. The Beck II, as it was called, had its basis in the theory that such an A-V fistula could provide a large amount of retrograde flow into the coronary system via communication between the venous and arterial sides of the circulation. Unfortunately, the patient, a 48-year-old man who had suffered from angina for 5 years, died 1 day after surgery. After a short period of popularity, this operation fell into general disuse. However, hearing Beck's paper stimulated my interest in the possibility of surgically treating coronary artery occlusive disease.

Early Canine Studies. One year later, in 1949, as an assistant surgical resident at Stanford, I began a research year in the surgical animal laboratory, trying to develop a dog model of coronary artery disease that could be used to evaluate the effectiveness of possible surgical therapeutic approaches. Figure 1 shows a dog's heart with an ameroid constrictor around the left anterior descending coronary artery and a saphenous vein bypass from the aortic arch to the distal left anterior descending coronary artery (LAD). I tried a saphenous vein as the conduit after learning of Kunlin's[1] use of a reversed saphenous vein for femoral–popliteal bypass. Anastomosis of the vein to the coronary artery was facilitated by elevating it away from the beating heart with loop sutures. I was trying to develop a method of occlusion of the vein bypass external to the chest when my year of animal research ended and I was re-immersed into a busy residency.

As a senior resident and subsequent faculty member at Stanford, I tried poudrage of the pericardium in an effort to create new avenues of arterial flow to the epicardium, but had little success. During these same years, Angelo May,[2] a surgeon friend in San Francisco, invented a corkscrew instrument to endarterectomize the LAD coronary artery. Fortunately, I did not try it in a patient but I did have the opportunity to observe, on closed-circuit television, Charles Bailey of Philadelphia use it in the beating heart with a disastrous result. Needless to say, coronary endarterectomy was not safe until cardiopulmonary bypass became available.

Transaortic Coronary Endarterectomy. In 1962,[3] I performed the 2nd successful transaortic coronary endarterectomy to be reported, after that of Dubost in Paris in 1960.[4] His patient had syphilitic blockage of the right coronary ostium, while mine had arteriosclerotic occlusive disease of the ostium. Distal to the blockage, my patient's right coronary artery appeared to be normal on a postoperative angiogram. This operation also had the distinction of being documented by preoperative and postoperative supra-aortic bolus arteriography. I used conventional cardiopulmonary bypass with continuous open perfusion of the left coronary artery, as opposed to Dubost's cardiopulmonary bypass with profound hypothermia. Figure 2 is a drawing of the operative approach that I used.

Selective Coronary Arteriography. It is of great historical interest to note that Sones, a pediatric cardiologist at the Cleveland Clinic, performed the 1st selective coronary arteriogram in 1958 quite by accident.[5,6] He was attempting to inject a large bolus of contrast medium retrograde into the left ventricle, in the hope that some of it would enter the coronaries. At that time, it was believed that direct injection of even a few cubic centimeters of dye into a coronary artery would be fatal. During the injection, he found that about 30 cc of contrast solution had gone into the

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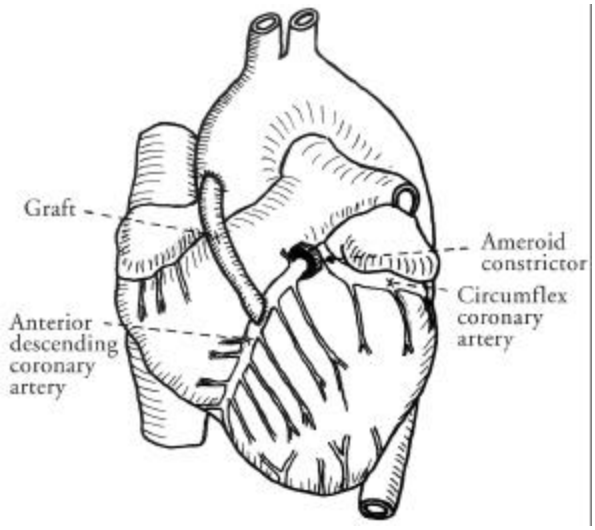

Fig. 1 *Diagram of a dog's heart with an ameroid constrictor around the left anterior descending coronary artery (LAD) and a saphenous vein bypass from the aortic arch to the distal LAD.*

right coronary artery, rather than into the left ventricle. Injection was halted, but the heart had stopped; Sones immediately pounded his patient's chest, and sinus rhythm resumed.* Because the visualization was much superior to that achieved by root injection and because the patient had survived the procedure, Sones then proceeded to develop the technique of selective coronary arteriography that became available clinically in the mid 1960s, and ultimately led to the explosive application of direct coronary artery surgery. Subsequently, at the Cleveland Clinic alone, hundreds of thousands of coronary arteriograms have been performed.

The Vineberg Procedure. In the 1950s and early 1960s, the only operation in use for coronary artery occlusive disease was the Vineberg procedure.[7] This consisted of the implantation of an internal mammary artery (IMA) into a left ventricular myocardial tunnel. I myself did the operation during the early 1960s because its mortality rate was low and it did seem to ameliorate angina in many patients. Although there was considerable skepticism about the value of this procedure, Sones was now able, with his selective coronary angiograms, to show interconnections between the IMA implant and branches of the coronary arteries.[8] He later reported[9] on angiographic assessment of 1,100 internal mammary implants performed at the Cleveland Clinic up to 1968 in which the implant was patent in 92% of patients and IMA–coronary artery communications were observed in 54%. It is of interest that in 1968–69, when the Cleveland Clinic was starting to perform direct coronary artery bypass grafting with saphenous vein conduits, they were still doing Vineberg procedures, especially double implants.

Myocardial Boring. Because of the apparent efficacy of the Vineberg operation, my associate Akio Wakabayashi and I thought that making connections between the left ventricular cavity of the heart and branches of the coronary arteries might do the same. In 1967, we reported animal experiments that used this technique, which we called myocardial boring.[10] We learned at that time that Sen[11] had performed similar experiments and had called his acupunctured animal hearts "snake hearts" because the snake does not have coronary arteries. I never did the procedure on human beings because of our work on coronary artery bypass, but others[12] revived myocardial boring 35 years later, using a CO_2 laser. I do not expect it to be any more successful in supplying increased coronary flow than was the Vineberg procedure.

Coronary Artery Bypass Grafting in Dogs. In 1966, Wakabayashi and I, in experimental studies[13-15] on dogs, were the 1st to perform aortocoronary vein bypass under cardiopulmonary support as we know it today. Reversed saphenous vein bypasses were performed from the ascending aorta to the circumflex coronary artery on 25 dogs under cardiopulmonary bypass, followed by ligation of the circumflex coronary artery. Of the 10 long-term survivors, 9 were euthanized in 1969, and 1 was kept as a pet and euthanized in old age 13 years after bypass, in 1980.[16] Figure 3 is a cast of this animal's heart showing a widely patent, well epithelialized, proximal aortic–venous anastomosis. The vein itself was thin-walled, pliable, and without calcification. Its wall was slightly thickened and no valves were identifiable. The distal anastomosis to the circumflex coronary artery showed narrowing at the heel of the vein graft, but the toe side was widely patent. Microscopic examination showed very minimal intimal reaction. There was no cellular infiltrate and the anastomoses showed continuous epithelialization. At that time, we concluded from these animal experiments that reversed saphenous vein bypasses should originate separately from the ascending aorta, that an arrested quiet heart is necessary for the most accurate distal vein–coronary artery anastomosis, and that the heart is best protected during arrest with ice slush.

Coronary Flow with Vineberg Implants vs Direct Coronary Bypass. We compared dogs in receipt of Vineberg internal mammary implants with dogs in receipt of aortocoronary bypass grafts[13] and found that the Vineberg animals did develop anastomoses from the mammary artery to small branches of the coronary arteries (Fig. 4). The mean flow through direct coro-

* Shirey EK. Personal communication; March 2001.

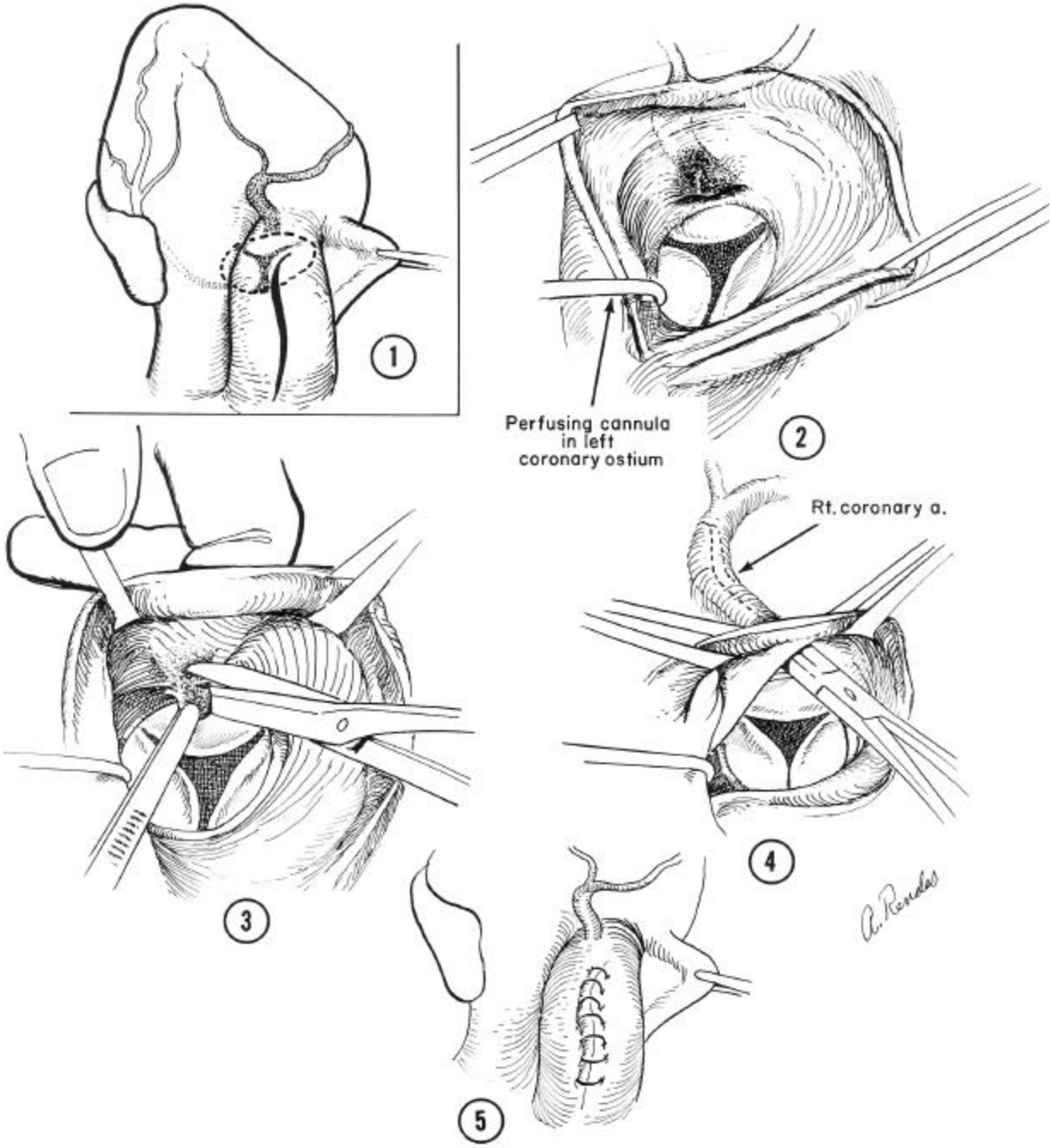

Fig. 2 *Operative procedure for ostial coronary endarterectomy: 1) ascending aortotomy; 2) constant perfusion of the left coronary ostium; 3) piecemeal removal of atheromatous ostial blockage; 4) probing proximal coronary artery; and 5) closed aortotomy.*

nary artery bypass grafts increased about 2-fold when the coronary artery was occluded proximal to the anastomosis, which suggested that in the absence of such occlusion the graft was carrying about half of the blood perfusing the distal coronary artery; further, it suggested that a direct graft has the capability of carrying the entire blood flow, in the event of complete occlusion of the proximal coronary artery. In the Vineberg animals, the mean flows were uniformly low. In contrast, all direct coronary artery bypass grafts had high mean flows and pulsatile flow patterns identical with those of the normal coronary artery. Additionally, all the direct bypass grafts responded to the administration of drugs in the same manner as do normal coronary arteries, while the Vineberg implants did not respond to these drugs.

In bypass animals 1 to 4 months postoperatively, blood flow patterns in both arterial and venous con-

duits were similar to those found in the normal coronary arteries, namely high flow during diastole and low flow during systole. However, there was a significant difference in mean flow between the arterial and venous grafts. The mean flow of the arterial grafts was 23 mL/min, whereas that of the saphenous vein grafts was 45 mL/min. This difference, we surmised, was due to the diameter of the grafts. Blood flow in both types of grafts (in common with normal coronary arteries) increased markedly in response to catecholamines and nitroglycerin.

Fig. 3 *Cast of dog's heart shows patent ascending aorta-to-coronary artery bypass via a reversed saphenous vein graft placed 13 years earlier.*

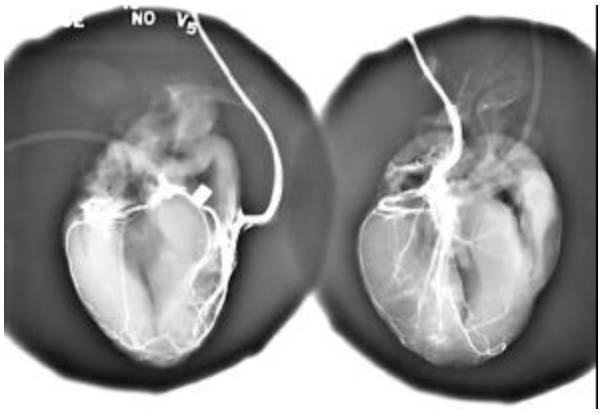

Fig. 4 *Angiogram 2 months after insertion of a Vineberg internal mammary artery into the left ventricle of a dog. Note the open communications with branches of the coronary artery.*

(From Wakabayashi A, Connolly JE.[13] Reproduced with permission of the Journal of Thoracic and Cardiovascular Surgery.)

Early Coronary Bypass Grafting in Human Beings. I performed my 1st human open-heart operation (atrial septal defect) on a patient under moderate, surface-induced hypothermia and inflow occlusion in 1957, and, in 1968, my 1st human coronary artery bypass with a single saphenous vein to the left anterior descending coronary artery. At that time, the surgical world was aware of Favaloro's 1st operation in 1967[17,18] but not of earlier operations by Goetz,[19] Garrett,[20] and Sabiston,[21] who had delayed publication of their results. Favaloro's operation in 1967 was an end-to-end bypass to the divided right coronary artery, while my 1st operation in 1968 was a distal end-to-side vein-to-coronary artery bypass, such as all surgeons now perform. I considered a distal end-to-side anastomosis preferable, because it enabled proximal as well as distal coronary flow. In my early operations, the heart was cannulated and attached to the extracorporeal circuit, but, to minimize the time on cardiopulmonary bypass, bypass was not begun until all reversed saphenous veins had been anastomosed to separate sites on the ascending aorta. After bypass was begun, the heart was electrically fibrillated and packed in sterile ice. While the distal anastomoses were carried out, the ascending aorta was declamped for 5 minutes of coronary perfusion at 20-minute intervals. At the end, the ice was removed and the heart defibrillated. A 5% mortality rate, early graft patency, and marked clinical improvement made me optimistic about the value of the new operation.

In 1972, I had the opportunity to do perhaps the 1st multiple coronary artery bypass operation in England, which I performed with saphenous vein grafts while I was a Visiting Professor at St. Thomas's Hospital in London. Several things were interesting about that operation. First, when the patient was taken through the doorway into the recovery room, I was stopped with the admonition that the anesthesia staff would completely handle the 1st few days of postoperative care, which of course I did not accept. Second, the patient was a senior pilot of British Airways, and several months later I received a check in the mail for £500, supplied by his supplemental private insurance! In the years that followed, this patient would call me whenever his flights took him to Los Angeles, to tell me how well he was doing.

As all cardiac surgeons operating in the early 1970s know, most of the leading cardiologists did not ac-

cept coronary artery bypass surgery. It was only a decade later, when younger cardiologists started to perform their own coronary angiograms, that cardiologists gradually accepted the operation. One of the major advances in the late 1980s was retrograde cardioplegia. My preference for the internal mammary artery as a conduit came later, but I continue to believe that the saphenous vein is the 2nd most practical conduit. More attention to the care of the saphenous vein during its harvesting is important. It is my belief that damage to the vein by overdistention during the search for branch leaks can result in later stenosis. I have had little experience with the radial artery, but if the donor-site complications can be solved, it might replace the saphenous vein as the preferable 2nd conduit.

In the early 1970s, I did some single coronary bypasses off cardiopulmonary bypass. Bypass to the proximal right coronary was relatively easy, because the artery could be lifted away, enabling the distal anastomosis to be performed free of the beating heart. I also did a few LAD bypasses with the beating heart, after the technique described by Ankeny.[22] I did not perform more such procedures, because multiple bypass surgery became routine—and that could not be performed, I thought, without a quiet heart.

Conclusion

In summary, the technique of coronary bypass surgery has changed surprisingly little over the past 20 years, except for minor refinements such as magnification and headlights. I have not had any experience with robotic coronary artery surgery, but I am watching its development with interest. Its greatest challenge will lie in performing multiple bypasses, which most patients need. The morbidity and mortality of coronary artery bypass surgery have fallen to very low levels, and the procedure is performed widely throughout the world. Its development is recognized both by the medical profession and the laity as one of the greatest advances in medical history. It was exciting to be involved in its early development.

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