History of coronary revascularization

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Abstract

Coronary revascularization evolved from an understanding of the relationship between coronary obstructions and the clinical manifestations they produce. Visualization of the coronary arteries in patients was necessary, and coronary arterography made that possible. Peripheral vascular surgical techniques were logically applied to the coronary circulation as technology for cardiac surgery had been developed. The concept of nonsurgical revascularization of the coronary arteries arose from the catheter-based opening of stenotic peripheral arteries. Interventional techniques including stenting are now finding their proper place alongside surgery as life-saving and life-enhancing therapies. Appropriate application of coronary revascularization in addition to modern medical therapy is now a principal focus.

Keywords: Coronary angioplasty; coronary artery bypass graft surgery; percutaneous coronary intervention; revascularization stenting

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Introduction

Revascularization of coronary arteries could only be realized from an understanding of the function of coronary arteries. It is not the intention of this paper to recount the history of cardiology, but it is interesting to reflect on the fact that Galen's flawed concepts of the circulation were promulgated from the second century until the renaissance. Had Leonardo da Vinci had enough time, this genius would probably have developed all approaches to revascularization, and perhaps he did and the drawings were lost. I think our modern experimental methods, as they relate to coronary revascularization, were understood by the man who made one of the greatest contributions to public health, Edward Jenner (1749–1823), the discoverer of the vaccine against smallpox. Jenner's bedside observations and postmortem examinations led him to link angina pectoris with coronary obstructions. Sir James MacKinzie (1853–1925) subsequently advocated the ischemic origin of angina and its relation to coronary obstructions. Amazingly little was added or could be added to the concept that something could be done about this until technology developed that could enable investigations in living patients. Without Roentgen, nothing would have been seen. Without Forssman, Klein, Cournand and Richards, catheterization of the vascular system would not have been possible, and without Sones the chance to intervene would not have been appreciated.

Although there were other approaches to the indirect visualization of the coronary arteries, it was not until Mason Sones inadvertently injected a coronary artery in 1958 and subsequently developed direct coronary arteriography, that the many ideas of how to perform coronary revascularization could be perfected (Fig. 1) [1].

Surgical revascularization

With the availability of coronary arteriographic images, it became conceivable that coronary revascularization could be accomplished. The angiographic extent and prognostic implication of

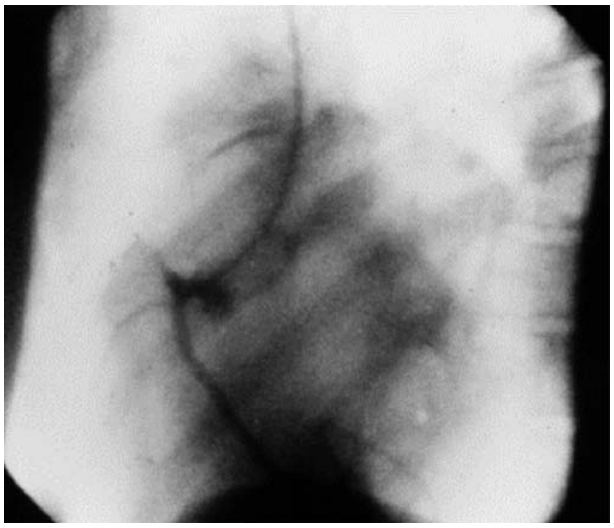

Fig. 1 *Cine frame from the first selective coronary arteriogram taken by Mason Sones on 30 October 1958. Reproduced from Ryan [1] with permission.*

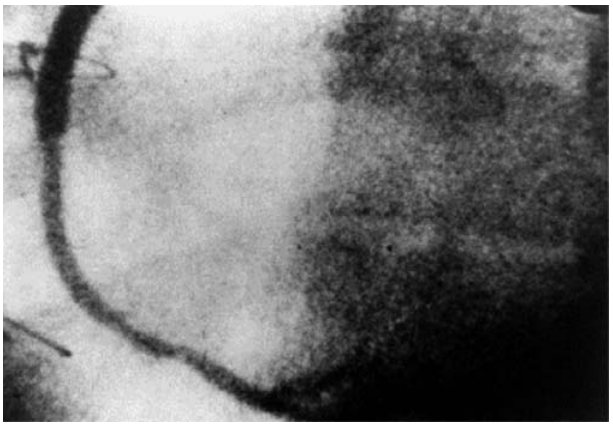

Fig. 2 *Cine frame taken by Sones of the first aortocoronary saphenous vein graft inserted by Rene Favaloro in May 1967. Reproduced from Ryan [1] with permission.*

coronary heart disease stimulated interest in doing something about it. Studies from the Cleveland Clinic showed very different outcomes of medical therapy based on the number of vessels with obstructions [2]. The Vineberg procedure of placing the bleeding internal mammary artery into a tunnel in the left ventricular myocardium and waiting for collaterals to form was soon replaced with direct revascularization using saphenous vein grafts. Leading this effort was Dr Rene Favaloro. Others had performed patch grafting of the coronary, developed by Senning [3], and a coronary artery bypass graft procedure had been performed as early as 1964 by Garrett when a complication of a coronary endarterectomy occurred [4]. However, it was Favaloro more than others who pioneered the saphenous vein bypass approach (Fig. 2). Among others who were pushing the envelope were Dudley Johnson of Milwaukee, who showed that multiple grafts to distal coronary segments could address diffuse disease, and George Green of New York, who performed direct internal mammary to coronary anastomoses. The techniques evolved rapidly with advances in anesthesia, cardiopulmonary bypass, myocardial protection and surgical equipment and supplies. By 1974, the Cleveland Clinic coronary artery bypass grafting surgery mortality rate was only 1.4%, and graft patency was 84% [5]. The stage was set for trials of the technique. The National Heart, Lung and Blood Institute funded the Coronary Artery Surgery Study (CASS) [6]. The randomized CASS enrolled 780 patients who were mildly symptomatic or had no symptoms, and although there was no overall survival benefit of revascularization, the patients with abnormal left ventricular function and three-vessel or proximal left anterior descending (LAD) artery plus circumflex disease did benefit. Other trials, such as the VA Cooperative Trial [7] and the European Coronary Surgery Study [8], studied more symptomatic patients. Based on those trials, surgical revascularization for patients with more extensive disease became the recommended treatment to improve survival. Following those trials, all started in the 1970s, information about surgical revascularization was primarily gained from registries and observational data. For significantly symptomatic patients, surgery usually eliminated angina and the technique flourished.

Percutaneous revascularization

The idea of percutaneous revascularization grew from a confluence of the radiographic knowledge of the coronary pathoanatomy, the success of bypass surgery and the technical development of peripheral vascular revascularization pioneered by Charles Dotter of Portland, Oregon. It was the crude coaxial catheter technique developed by Dotter that inspired Andreas Gruentzig to conceive a catheter-based method of revascularizing narrowed or obstructed coronary arteries with a balloon catheter. After gaining experience with the noncompliant balloon built for peripheral vascular use, animal experiments confirmed that he could open obstructed coronary arteries with a small catheter-delivered balloon and eliminate the obstruction (Fig. 3). In September 1977, the first patient with disabling angina and a proximal left anterior descending stenosis underwent angioplasty (Fig. 4). The first successful cases were presented

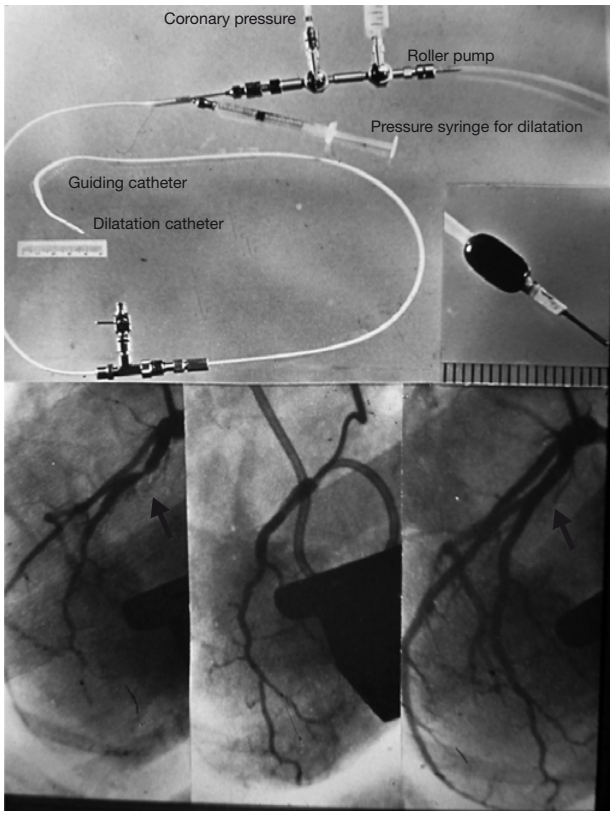

Fig. 3 *Early dog experiments by Andreas Gruentzig. Photo provided by Maria Schlumpf, Zurich.*

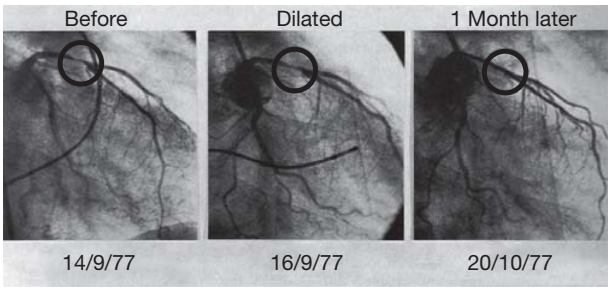

Fig. 4 *First patient to undergo successful percutaneous transluminal coronary angioplasty.*

at the American Heart Association's scientific sessions later that year to an astonished audience that included Mason Sones. The rush was on to visit Gruentzig in Zurich and adopt the technique [9]. It should be pointed out that angioplasty was first applied to treat angina pectoris in patients who had suitable stenoses and otherwise would have had surgery [10]. Support for Gruentzig's efforts in his home institution was mixed. Interestingly, the surgeon who offered support and encouragement was the same Ake Senning who had first developed the technique of endarterectomy and patch grafting to provide coronary revascularization before the emergence of vein graft surgery. Although Gruentzig was able to conduct live demonstration courses and to train the early adopters, he became frustrated with restrictions placed on him in Zurich and was convinced to join the laboratory of the present author at Emory University in Atlanta in 1980. Many pioneers expanded percutaneous coronary revascularization. John Simpson developed a catheter that could be placed over a guidewire. Subsequent steerable guidewires enabled treatment of more remote coronary lesions. One of the greatest successes of percutaneous revascularization has been the emergency reperfusion of occluded coronary arteries causing acute myocardial infarction. The work of Raymond Erbel in Germany and Geoffrey Hartzler in Kansas City was pivotal in perfecting this approach, which has been life saving and has gained worldwide acceptance.

The main drawbacks of angioplasty were the unstable lumen post procedure leading to acute occlusion, and the later restenosis that occurred in over 30% of patients. The "new device era" evolved to try to overcome these issues. Multiple devices, including atherectomy catheters and lasers were developed to remove plaque but have been largely abandoned. Only stents have remained and have become the default percutaneous therapy. Stents stabilize the artery acutely, dramatically reducing the need for emergency surgery after a failed angioplasty. Restenosis caused by excessive healing response was a continuing problem until antiproliferative drugs such as paclitaxel and rapamycin were incorporated onto the stents.

Percutaneous revascularization has been tested against surgical intervention and against medical therapy alone. From the earliest trials, such as the Emory Angioplasty Versus Surgery trial [11] and the Bypass Angioplasty Revascularization Investigation [12], it was learned that percutaneous approaches could be employed for appropriate multivessel patients without increasing the risk of death or myocardial infarction compared to bypass surgery. After major advances in stenting and surgery, the most current comparison, the SYNTAX (SYNergy Between PCI With TAXUS and Cardiac Surgery) trial [13], identifies patients who can safely undergo stenting and other more complex subsets that have superior outcomes with surgical revascularization. Although there is little debate about revascularization for patients with acute coronary syndromes, the use of revascularization for stable coronary disease remains controversial. The Clinical Outcomes Utilizing

Revascularization and Aggressive Drug Evaluation (COURAGE) trial [14] and the Bypass Angioplasty Revascularization Investigation 2 Diabetes (BARI 2D) trial [15] selected patients with known coronary anatomy for revascularization or medical therapy only. A clear survival advantage for revascularization could not be shown in these patients with less than severe obstructive disease. A current trial using fractional flow reserve to document major artery flow-limiting stenoses favors revascularization [16], and an ongoing trial, ISCHEMIA (International Study of Comparative Health Effectiveness with Medical and Invasive Approaches), will study patients without disabling symptoms who have extensive ischemia on noninvasive perfusion scanning.

A population of major interest since the BARI trial is those patients with diabetes and multivessel disease. When the trials of angioplasty and those using bare metal stents were analyzed using patient-specific data, an advantage for surgery over percutaneous intervention was found [17]. The most definitive study in patients with diabetes using drug-eluting stents, the FREEDOM (Future REvascularization Evaluation in patients with Diabetes Mellitus) trial, will report the 5-year outcome at the American Heart Association's scientific sessions in November 2012. Aside from the remaining questions about the value of coronary revascularization for the prevention of premature death and myocardial infarction, the benefit of relieving obstruction and restoring nutritive coronary flow is the most effective therapy for angina pectoris and disabling symptoms. A more detailed review of the history of surgical and percutaneous revascularization can be found in a monologue by Drs Favaloro, Tom Ryan and the present author [5,18–20].

Conclusion

Now, 83 years from the first coronary catheterization, 54 years since the first selective coronary arteriogram, 50 years since the development of surgical coronary revascularization, and 35 years from the first percutaneous coronary revascularization, we have learned much about the effectiveness of restoring coronary blood flow. It is not surprising that the more obstruction, the more ischemia, the more symptoms – the greater the benefit of revascularization. The next frontier is to understand better how to retard the development of coronary obstructions through metabolic interventions, and how to identify and interdict the catastrophic events resulting from sudden coronary occlusions. •

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