

Myocardial revascularization in the XXI century

Revascularização miocárdica no século XXI

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Always concerned with the historic rescue of cardiovascular surgery, the Brazilian Journal of Cardiovascular Surgery (BJCVS) publishes the following article, written by Dr. Luis Dallan and Fábio Jatene, respectively, Associate Editor and former Editor-in-Chief of BJCVS. In a text rich in detail, they write about the history of CABG, from its beginnings until prospects of the currently consecrated technique and that should be aware of all cardiovascular surgeons.

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HEART: BODY THAT UNTOUCHABLE

Despite the acceptance and routine use of cardiac surgery nowadays, it was not always so. In the late 19th century and early 20th century, the surgical treatment of heart was considered beyond any question. One of the clearest examples of this view was the declaration by Theodor Billroth in the meeting of the Medical Society of Vienna, 1881, who stated: “*The surgeon who wished to preserve the respect of his colleagues would ever attempt to suture the wound of the heart*” [1].

Even in the early decades of the 20th century heart surgery gained great expression. Proof of this is the absence

of any mention of it in the classic book “The Century of the Surgeon”, published in 1957 by Jurgen Thorwald [2]. However, from the years 1950, cardiopulmonary bypass has gained great development and became progressively employed in clinical practice. This allowed the real principle of heart surgery and generated its fantastic boost, which did not cease until the present day.

THE PRESTIGE OF CARDIAC SURGERY

Despite a timid start to the second half of the 20th century, from the 1960s the cardiac surgery has gained tremendous visibility. The figure of the cardiovascular surgeon came to

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be celebrated publicly, with much prestige as astronauts. Names like Dr. Christiaan Barnard, Denton Cooley, Michael DeBakey and Norman Shumway became known for the huge audience, especially after the advent of heart transplantation. In Brazil it was no different. It was up to teachers as Euryclides Zerbini and Adib Jatene assume this leadership [3].

ARTERY BYPASS GRAFTING: ADVANCES ESTABLISHED

Today, surgical treatment of coronary artery disease is probably the most studied topic among all medical specialties. This fact certainly makes the method more attractive and greatly honors who proceeds. Moreover, it also keeps the surgeon under constant stress and challenge.

Historically, CABG is involved in a huge visibility. Besides the possibility of imminent death compared to procedures that manipulate the coronary arteries, the alternatives available today, such as angioplasty, contribute to the debate about what is the best procedure for coronary disease.

BEGINNINGS OF ARTERY BYPASS GRAFTING

The notion of coronary artery disease was brought to the Royal College of Physicians in 1768 by William Heberden and published in 1772 in the Transactions of the Medical College. However, the relationship between this disease and angina was not completely elucidated, and only in 1876 Adam Hammer [4] suggested that the angina pectoris and myocardial infarction could be attributed to the reduction or interruption in coronary blood flow when at least one of the arteries of the heart was compromised. This allowed better understanding of coronary artery disease, enabling the programming of its treatment.

The methods of myocardial revascularization were not established from day to night, neither linearly. Initially, the procedures used were abandoned to be later reproduced again and sometimes were considered ideal.

In the first decades of the 20th century countless procedures on the heart were used, seeking the relief of angina symptoms. These methods were all indirect and ineffective. Among them, the one proposed by Beck et al. [5] at the Cleveland Clinic in 1935, which sought to obtain collateral circulation with the involvement of structures such as pericardial fat, pectoral muscle or omentum on the chiseling epicardium.

Only in 1951 Vineberg et al. [6], after extensive experimental study involving the development of collateral circulation, proposed the implant of the internal thoracic artery in the left ventricle muscle. For that, they performed a tunnel amid the ventricular wall, which was posited within

the internal thoracic artery. The branches of this artery were kept bleeding, aiming to establish future connections with ischemic myocardial arterioles. This technique achieved good results and was an important treatment of angina for several years.

DIRECT MYOCARDIAL REVASCULARIZATION: A CONTROVERSIAL START

Certainly the great impetus to the development of myocardial revascularization was the advent of coronary angiography in 1958, assigned to Sones et al. [7] at the Cleveland Clinic. However, the idea of directly revascularize the myocardium met resistance until the mid 1960s. On May 2, 1960, Goetz et al. [8] performed the first successful coronary artery bypass grafting. They anastomosed the right internal thoracic artery with the right coronary artery, using mechanical suture with tantalum ring. Despite the patency be maintained for 1 year, they were strongly criticized by fellow clinicians and surgeons and the procedure was deemed unsafe and of experimental nature. Goetz never performed any revascularization [9].

In 1962, David Sabiston performed a saphenous vein graft with a patient who died after three days of neurological complications. The case was only reported in 1974. In 1964, Garrett et al. [10] performed at Methodist Hospital in Houston, the first successful coronary artery bypass grafting with saphenous vein after failure in coronary artery endarterectomy. An angiogram after seven years demonstrated graft patency and the case was reported in 1973.

ARTERY BYPASS GRAFTING: EXCELLENCE TECHNICIANS THAT HAVE PERPETUATED

Internal Thoracic Arteries

In Leningrad, Russia, Kolessov [11] performed on 25 February 1964, the first anastomosis of the left internal thoracic artery to the anterior interventricular branch of the left coronary artery. The technique involved the left thoracotomy without the use of cardiopulmonary bypass. At the time, the method was not well received in the international media. One reason was the observation that the immediate flow of the left internal thoracic artery was lower than that of saphenous vein graft.

Since 1967, René Favaloro, working in line with Mason Sones at the Cleveland Clinic, popularized and gave a scientific mark to the saphenous vein graft in the treatment of coronary heart disease [12]. After just one year, in 1968, this procedure for myocardial revascularization was also performed in Brazil by Dr. Zerbini and Adib Jatene rapidly being reproduced by many groups across the country [13,14].

Again, it fell to a study performed at the Cleveland Clinic in 1986, by Loop et al. [15], promote strong impact on the history of coronary artery bypass grafting. In it, the authors found the long-term superiority of the left internal thoracic artery when comparing to the saphenous vein, when anastomosed to the anterior interventricular branch of the left coronary artery. After 10 years of follow-up, the observation of patency over 90% chose the left internal thoracic artery as the standard procedure to revascularize this branch of the left coronary artery. More recently, Lytle et al. [16] extended similar studies for a longer period. The observation of 90% of patent grafts over 20 years after surgery gave the left internal thoracic artery the condition of most reliable therapy that is known for treating coronary artery disease.

The right internal thoracic artery when used for the right coronary artery and its branches, showed no similar patency results to those obtained when used for the left coronary artery system. A major advance in CABG was its use *in situ* by retroaortic via in branches of the left coronary artery. This technique was described in our midst by Puig et al. [17] in 1984. This thoracic artery also came to be used for branches of the circumflex artery as a composed arterial graft with the left internal thoracic artery, or as a free graft. Recently, various studies have demonstrated the possibility of using the right internal thoracic artery *in situ* by antegrade via in the anterior interventricular branch of the left coronary artery, with excellent immediate results [18-21].

ALTERNATIVE ARTERIAL GRAFTS

Radial, gastroepiploic, inferior epigastric and lateral circumflex femoral arteries

In 1971, Carpentier had already introduced the radial artery as a graft for coronary revascularization alternative, however, the initial results were disappointing. Currently, its use was restored, especially after the advent of antispasmodic drugs. [22] This also motivated the development of alternative proposals to prevent its spasm [23]. With the dissection, a graft from 15 to 20 cm can be obtained, which can be used by means of proximal aortic anastomosis, or in "Y" with the internal thoracic artery. Its dissection can be simultaneous with the chest opening and often is ready before the end of the internal thoracic artery dissection. That was one of the reasons that led to the temporary abandonment of its use because its tissue structure suffered significant damage when subjected to prolonged ischemia. Today is consensus that after the dissection, one should keep it in its bed, covered with gauze soaked in papaverine to reverse any spasms, until its use.

Alternatively, it can be removed only after the systemic administration of heparin immediately before making its proximal anastomosis. Thus, it gets expanded with the

systemic pressure, without manipulation, and therefore less risk of injury to its layers (particularly the endothelium), decreasing the chance of perioperative spasm. Today we know that, given its feature of spasticity, its use should be avoided in coronary arteries with lesions smaller than 70%, due to the risk of flow competition, which could eventually lead to the occurrence of string sign (diffuse tapering throughout graft) [24]. The hypothesis that the proximal anastomosis could interfere with the graft flow has not been proven [25].

In 1987, Pym et al. [26] described the use of gastroepiploic artery segments. It originates, respectively, from hepatic, gastroduodenal and pancreaticoduodenal arteries. Located on the anterior surface of the greater gastric curvature, being responsible for the irrigation of the lower two-thirds of this curvature. Its use in cardiac surgery reserves mainly to cases where one seeks the exclusive use of arterial grafts in CABG. Usually, it is used *in situ* to coronary branches of the underside of the heart, or in combination with other arteries such as the internal thoracic and radial.

In the 1990s, Puig et al. [27] introduced the inferior epigastric artery. Anatomically, originates from the external iliac artery, and is situated in the lower third of the abdominal wall, between the rectus abdominis muscle and its posterior sheath. In this region, it enters the rectus abdominis muscle, dividing into several branches, which will anastomose with branches of the superior epigastric artery. It is indicated in young patients, or the unavailability of normal grafts, as grafted patients or patients with varicose veins in the lower limbs.

The descending branch of the lateral femoral circumflex artery has also been studied in this line alternative. In 2003, Fabrocini et al. [28] studied by cineangiography 81 among 147 patients in which the graft was employed. The patency at the end of 1 and 3 years was respectively 97% and 93%. A similar study in Brazil also showed high short-term patency (92% at 90 days) and positive remodeling of the luminal diameter [29]. The authors concluded that the descending branch of the lateral femoral circumflex artery is a promising option for arterial graft.

GRAFTS USING SAPHENOUS VEIN

The use of saphenous vein devoted the coronary artery bypass grafting and is still used in many centers to complement the revascularization of determined coronary arteries.

It is known that the patency of saphenous vein is less than that of human internal thoracic arteries. This is due in part to the fact that the structure of the saphenous vein can be affected by high pressures of distension, either in its preparation or when positioned as coronary artery bypass graft [30,31].

The dissection of the saphenous vein should be performed through small incisions, approximately 4 cm in length, leaving a bridge between each of intact skin incision. There are also auxiliary devices that allow withdrawal of a less invasive manner, with mini-incisions of a few millimeters.

Modern techniques of dissection demonstrated that reduced distention pressure of the veins during preparation minimize the risk of endothelial lesions, further improving the results [32]. Furthermore, drugs that reduce systemic rates of fat and platelet adhesion have demonstrated an influence on long-term patency of these grafts.

MINIMALLY INVASIVE TECHNIQUES

Revascularization without cardiopulmonary bypass

The search for less invasive procedures led to the development of techniques of revascularization without cardiopulmonary bypass. The possibility of performing coronary artery bypass grafting without its use was strengthened in the 1990s. Buffolo et al. [33] and Benetti et al. [34] as well as other groups began to emerge in the world demonstrating the benefit of this technique in reducing morbidity and mortality, especially by the reduction of neurological problems. Initially reserved for treatment of coronary lesions only and located on the anterior wall of the heart, this tactic was quickly extended to patients with injuries in two or more vessels. We developed different models of heart stabilizers, which allowed the reduction of regional cardiac motion. It was also used in shunts that enabled the maintenance of irrigation during the distal anastomosis, avoiding eventual ischemia and hemodynamic deterioration. This provided more comfort for the anastomosis in these surgeries [35]. The issue became controversial and numerous comparative studies have been developed, with conflicting results. Most of them relied on less inflammatory reaction surrounding the procedure. But certainly, the great benefit of the method is to avoid excessive manipulation of the ascending aorta. Thus, although it is desirable to minimize the use of cardiopulmonary bypass on myocardial revascularization, it is still a major challenge for modern heart surgery to avoid it in all cases.

Myocardial revascularization by miniaccess

In seeking to maintain the benefits of surgical treatment of coronary artery disease, with less invasive techniques with less surgical trauma, we have sought to achieve myocardial revascularization with the internal thoracic artery by minithoracotomy, avoiding cardiopulmonary bypass and sternotomy. The first report of myocardial revascularization by this miniaccess was described by Benetti & Ballester [36] in 1995. In two patients, the authors managed to dissect the left internal thoracic artery to left

anterior minithoracotomy, with the aid of videothoracoscopy and anastomosed it to the anterior interventricular coronary artery. Subramanian et al. [37] also reported experience with CABG minithoracotomy, but with direct dissection of the left internal thoracic artery, without using a thoracoscope.

A major concern of this new technique was the quality of the anastomosis of the internal thoracic artery to the coronary artery, without cardiopulmonary bypass and minimal access surgery. At the beginning of the experiment, some authors have reported problems in coronary anastomosis and early reoperation between 10% and 15% of patients [38,39]. With the advent of regional coronary stabilizers, coronary anastomosis on the beating heart began to be performed more safely and myocardial revascularization without cardiopulmonary bypass with full sternotomy or miniaccess now has greater acceptance by cardiovascular surgeons [40-42].

ROBOTIC SURGERY IN CORONARY ARTERY BYPASS GRAFTING

Various techniques of minimally invasive CABG have been facilitated by appropriate endoscopic view during dissection of the internal thoracic artery. The use of these techniques in cardiovascular surgery has provided a less invasive new alternative for patients with coronary heart disease. The surgery can be performed with better aesthetics, enabling faster recovery, less hospital stay [43].

In Brazil, the robotic dissection of left internal thoracic artery was initiated in 2001 with the use of videothoracoscopy guided by robotic arm (AESOP), integrated with the drive system of the optical fiber, through voice communication [44]. Importantly, the improvement and application of these techniques require a training step and an intensive learning curve [45,46].

Several recent studies have demonstrated the advantages of these minimally invasive procedures. In our environment, Milanez et al. [47] demonstrated the possibility of dissection of the left internal thoracic artery through robotics, with better outcomes compared to those obtained by its traditional dissection. The ultimate goal would be the feasibility of complete myocardial revascularization with the aid of thoracoscopy, which is performed without opening the chest [48-50].

In this sense, robotic assistance has gradually gaining ground in clinical practice, aiding in dissection of the internal thoracic artery and performance of coronary anastomosis [51,52]. CABG robotic surgeries with chest fully enclosed are a reality in some centers in the United States and Europe, and the anastomoses performed with the use of mechanical devices, without the use of cardiopulmonary bypass. Despite initial reports with favorable results, the high cost of such equipment and the great difficulty in learning curve of

these procedures are limited to a few specialized centers worldwide.

All these innovations aim to optimize the results already achieved, with less aggression and less patient morbidity and mortality; some, however, still need to be incorporated routinely in daily clinical practice, making procedures more efficient, safe and reproducible.

HYBRID SURGICAL ROOM

The development and recent changes of cardiac surgery and interventional cardiology have demonstrated the need for installation of integrated catheterization laboratory to the operating room. These hybrid or high-tech rooms, as they are more commonly known, began to be idealized from the growth of minimally invasive cardiac surgery and the need for interventional cardiology in performing increasingly invasive and more complex procedures. The hybrid room is generally located within the operating room and used in less invasive, video-assisted or robotic surgeries requiring more sophisticated and complex imaging modality. They provide security for the surgery and allow the surgeon rapid assessment of the surgical outcome. More invasive and complex interventional procedures requiring rapid action of the cardiovascular surgeon and mechanical assistance are also performed in this room.

Currently, the hybrid operating room is a reality, not only in academic and research institutions, but also in general hospitals. The recent interest in these rooms has raised important questions about the use, standardization, dimensions and organization of material and personnel in these units.

CORONARY ARTERY BYPASS GRAFTING: CURRENT CONSIDERATIONS

Even today, the CABG remains an excellent therapeutic option for treatment of obstructive coronary artery disease, even in diabetic patients [53,54], in elderly patients [55,56] and in patients with low left ventricular ejection fraction [57]. Alternative procedures, such as using laser beams [58], stem cells [59] and even variations in the use of internal thoracic artery [60] have been described, but are part of the treatment of a special group of patients, which is certainly not fit into the daily routine.

It is clear that CABG surgery is a moment of transformation, as we can observe: surgery using only arterial grafts without the use of cardiopulmonary bypass, performed in a minimally invasive way, if possible with the help of robotics.

The aims of this surgery are basically relief in anginal symptoms, with consequent improvement in quality of life and increased survival. Especially in young patients, it seeks

a type of intervention alternative to drug or percutaneous therapy to maintain long-term outcomes, thus avoiding the recurrence of angina or cardiac events, thus minimizing the need for reoperation or reintervention.

Despite the tendency of employment the greatest possible number of arterial grafts in coronary artery bypass graft, due to higher patency internal thoracic artery and other arterial grafts, saphenous vein continues to be used due to the very good size and easy to obtain. Limitations such as graft failure in the long term have been circumvented by its proper preparation and systemic treatment of the patient, especially with controlling his blood pressure, and glycemic indices by using statins.

Moreover, the ITAs rarely develop atherosclerosis, their diameters are usually compatible with the coronary artery to be revascularized and its limitations in length can be overcome through skeletonization or employment as a free graft [61]. However, the use of both internal thoracic arteries requires more refined technique and increases the surgical time. Thus, the use of both internal thoracic arteries is not routinely performed on all services and in many subgroups of patients. This makes the utilization rates of internal thoracic arteries vary from 4% to 30%, even in countries like the U.S., Japan and some countries of Europe [62,63].

Currently, we know that in the long-term there is the remodeling of the internal thoracic arteries, which eventually suit their flow to myocardial bed receptor. Thus, the right internal thoracic artery has been preferred as a second arterial graft compared to the radial artery. Therefore, the use of left and right internal thoracic arteries, supplemented or not by arterial grafts or saphenous vein, is still the condition therapy used in the treatment of obstructive coronary artery disease.

In a nutshell, an achievement at low cost and minimally invasive manner (video-assisted or robotic) can be considered ideal in CABG, without the use of cardiopulmonary bypass, using arterial grafts and, if necessary, associated to hybrid procedures (minimally invasive surgery complemented by percutaneous performance).

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