Cabrol Graft Technique in Aortic Root Replacement: A Historical and Current Review

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Abstract:

In 1968, Bentall and De Bono reported a method for complete aortic root replacement involving side-to-side anastomoses of the right and left coronary arteries onto the aortic graft. This came to be known as the classic Bentall technique. In subsequent years, recognition of bleeding and pseudoaneurysm formation at the site of the side-to-side coronary anastomoses, among others complications, came to the fore. To address these issues, Kouchoukos developed his modification in which the coronary ostea, with a rim of aortic tissue, were detached completely from the aortic wall and anastomosed end-to-side onto openings in the main aortic graft. Cabrol et al in 1981 described an alternative technique in which a "moustache-shaped" interposition Dacron graft was used in a sub-group of patients whose ostea could not easily be brought into place. The ends of the moustache graft were anastomosed to the coronary buttons; then, the side of the moustache graft was anastomosed side-to-side to the main aortic graft. Several modifications of this surgical approach have been reported, as well as the complications developing in those who underwent the classic or modified Cabrol technique. We review this experience-positive and negative-here. Nowadays, the surgical treatment of aortic root aneurysm includes either a composite valve graft conduit (mechanical or biological valve), a stentless aortic root xenograft, or the popular valve sparing aortic root replacement. As all of these options require reimplantation of the coronary ostia onto the primary graft, several coronary reimplantation surgical techniques have evolved. This literature review aims to characterize the history, modifications, and reported outcomes of the classic Cabrol technique and its modifications.

Keywords: Aortic root replacement, coronary reconstruction. graft interposition, Cabrol graft, coronary button

INTRODUCTION

Reimplantation of the coronary artery ostea (right and left) onto the aortic graft is a requirement and a key stage during an aortic root aneurysm surgery. Among different techniques that have been developed, the first was reported in 1968 by Bentall and de Bono[1], who in a side-to-side fashion anastomosed the aneurysm wall carrying the coronary ostia onto the aortic conduit (Figure 1). In subsequent years, complications were noted in patients who had undergone the classic Bentall approach. Those complications included excess or uncontrollable bleeding at the time of surgery, as well as late pseudoaneurysm formation at the side-to-side anastomoses. To address those complications, Cabrol et al[2] reported in 1981 an alternative technique, applied in a sub-group of patients, in which a "moustache-shaped" interposition graft was anastomosed

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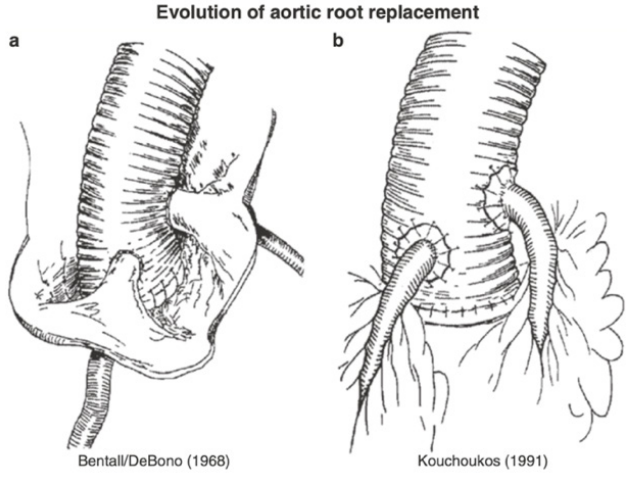

Figure 1. Techniques for direct coronary anastomosis onto the aortic graft. (**a**) Bentall/DeBono technique. Note how the coronary arteries remain part of the aortic carcass, which itself is brought up to the aortic wall and attached in side-to-side fashion. (**b**) Kouchoukos technique. Note that the coronary artery, with a surrounding "button" of aortic wall is detached completely from the aortic carcass and brought up for an end-to-end anastomosis to the new Dacron graft. (Reprinted with permission from Platis et al. [Platis IE, Kopf GS, Dewar MS, Shaw RK, Elefteriades JA. Composite graft with coronary button reimplantation: procedure of choice for aortic root replacement. Int J Angiol. 1998;7:41-5]).

in an end-to-end fashion onto each coronary ostium and in a side-to-side fashion onto the aortic conduit (Figure 2). Several modifications of this surgical approach have been documented. Furthermore, complications in those who received either the classic or modified Cabrol technique have been described by multiple authors. Although the current gold standard for composite graft or valve-sparing aortic root replacement is the "button-technique" described by Kouchoukos et al [3] (Figure 1), these Cabrol modifications remain critically useful in anatomic situations where direct coronary button reimplantation is not feasible. This need arises in case of specific anatomic irregularities that prevent safe, direct button reimplantation. This is usually related to inability of coronary buttons chronically displaced far away from the centerline of the aorta by massive aortic root enlargement ("giant root aneurysms"); such buttons may not be able to "reach" the much smaller replacement graft. Other potential situations include reoperations, where scarring prevents safe coronary button mobilization. Also, in cases where rotational mal-positioning of the coronary buttons produces torsion, this can be alleviated by an interposition Cabrol graft. The aim of this literature review is to characterize the history, modifications, and reported outcomes of the classic Cabrol technique and its modifications.

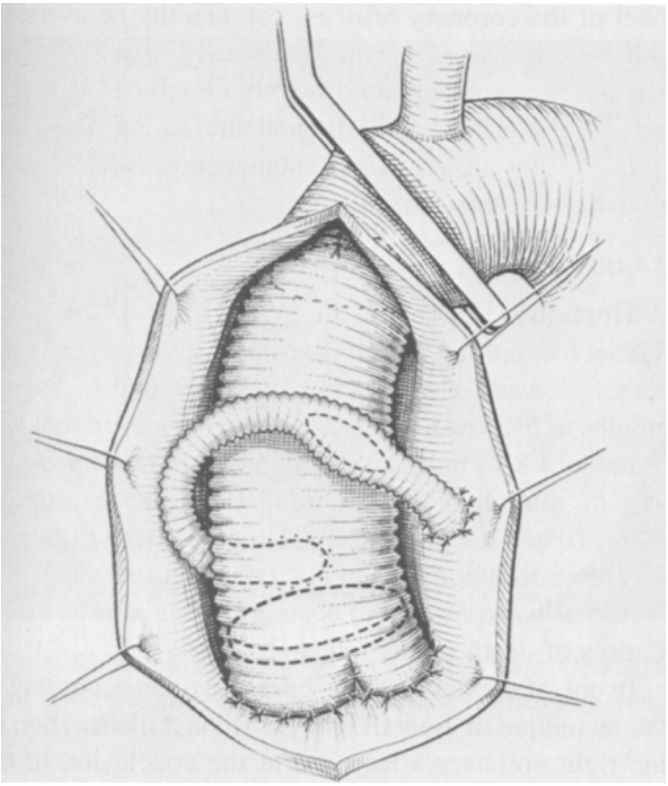

Figure 2. This Figure shows the aorta replaced by the "inclusion" technique. This is rarely used in the present era for ascending replacement; currently, resectional replacement is preferred. We use the original Cabrol diagram for its historical relevance. (Reprinted with permission from Cabrol et al.[2]). Note that the two ends of the small caliber Cabrol graft are anastomosed over the coronary ostea (right and left). This can be done onto the aortic wall or onto detached coronary artery buttons.

HISTORY

In 1956, prior to the development of coronary reimplantation surgical techniques, Cooley and De Bakey[4] reported the first successful supracoronary intervention for a fusiform aneurysm of the ascending aorta. With that report, the authors introduced the use of cardiopulmonary bypass in aortic aneurysm surgery. In 1964 Wheat et al[5] described successful replacement of the ascending aorta and aortic valve in a patient with an aneurysm extending proximal to coronary ostia. In this case, a tongue of aortic wall was left surrounding the two coronary ostia, allowing the sutures to be distant from the lumen of the ostia and thus reducing the risk of thrombosis and tension on the coronary arteries.

In 1968 Bentall and De Bono [1] described a ground-breaking surgical technique that took cardiac surgery by storm. Their one-page paper has become a classic in terms of clarity and efficient use of words and line drawings. In this bold, novel technique, the previously unapproachable coronary ostia were reincorporated into the side of the aortic graft through an end-to-side anastomosis (Figure 1). This came to be called the classic Bentall technique. Throughout 1970s, studies reported the difficulty in coronary reimplantation and suturing; the procedure was complicated by more than occasional intraoperative bleeding at the aortocoronary suture lines, or, later development of a pseudoaneurysm at the site of the coronary ostial anastomosis[6]. These difficulties were thought to arise from failure to incorporate the full thickness of the aortic wall (with the strong adventitia) into the coronary suture line.

Alternative techniques were developed to handle these problems. In 1975 Blanco et al[7] reported an end-to-end anastomosis of reversed saphenous vein segments between the coronary ostia and the main aortic graft. Zubiate et al[8] in 1976 described the use of saphenous vein grafts to "transpose the origin of coronary arteries" or to bypass more distally, to the standard coronary graft locations on the right and left coronary arteries. (Figure 3).

Neveux et al[9] reported an imaginative alternative technique for the setting of a low coronary ostium that would not allow direct and tension-free coronary reimplantation. In this surgical approach, by making a hole in the aortic graft that preserves the prosthetic wall as a lower flap of aortic prothesis, a trap door effect with a lower hinge was created (Figure 4). This allowed direct coronary reimplantation in cases of a low-lying coronary artery ostium. This technique essentially brings the aortic graft material "down to" the comfortable location of the coronary artery button.

In 1981 Cabrol and colleagues[2] reported their alternative technique in which each coronary ostium was anastomosed end-to-end to the ends of an 8 mm polyester tube graft, which itself was anastomosed side-to-side to the main aortic graft (Figure 2). In the subsequent years, several additional modifications of this Cabrol surgical technique were developed.

Also, as experience with full aortic root replacement grew, clinical patient outcomes were able to be assessed with the different techniques.

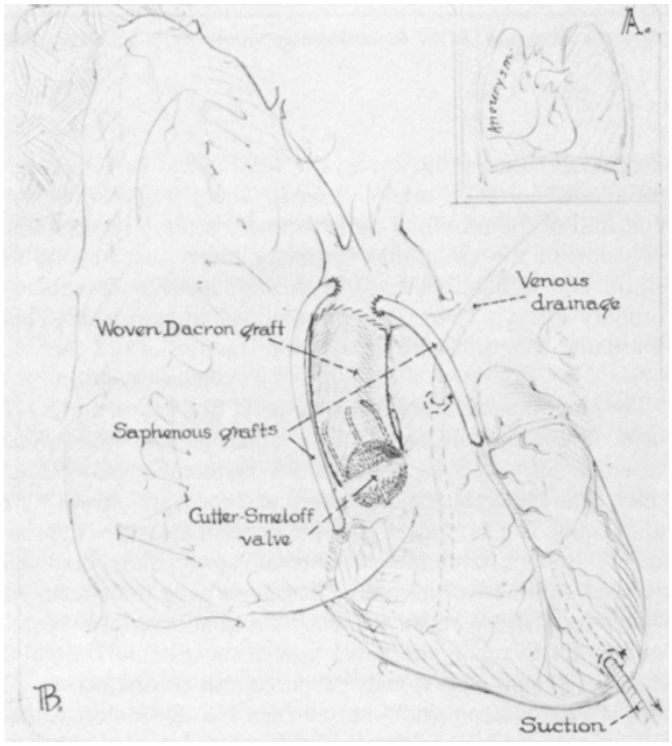

Figure 3. "Transposition of coronary arteries" origin using saphenous vein grafts (Reprinted with permission from Zubiate et al.[8]) This particular drawing, from the original authors, actually shows typical saphenous vein graft bypass to the coronary arteries themselves rather than to the coronary ostea.

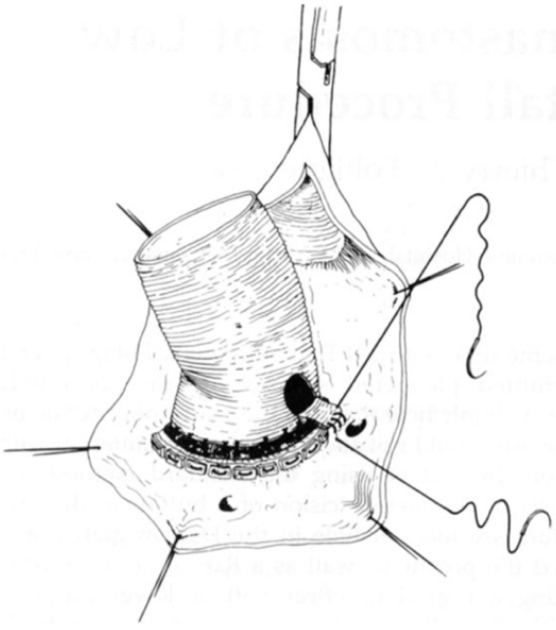

Figure 4. Direct reattachment of a low-lying coronary ostium (Reprinted with permission from Neveux et al.[9]) Note how maintaining some graft material as a lower flap brings the anastomotic construct lower, closer to the tight coronary artery.

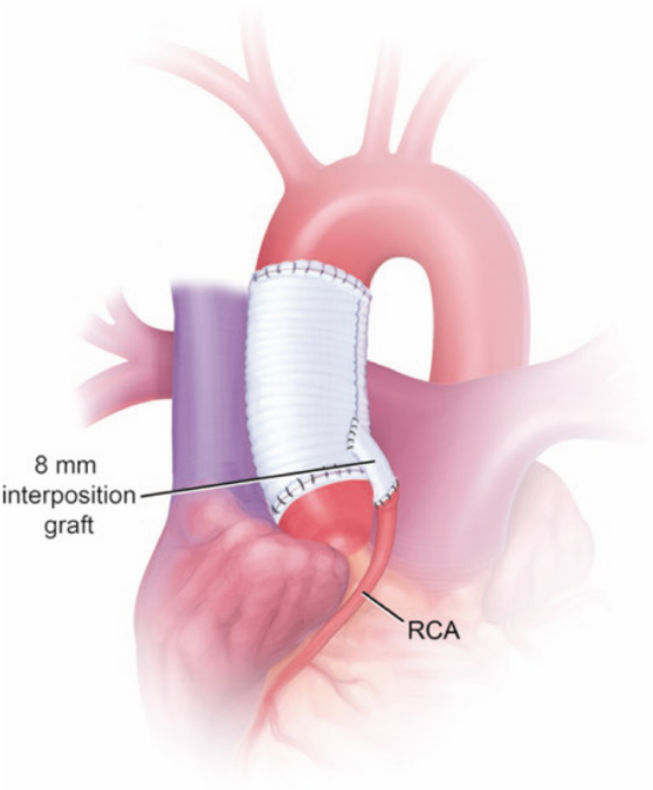

Figure 5. Coronary ostium reimplantation using a short interposition polytetrafluoroethylene graft (Reprinted with permission from Elefteriades et al. [Elefteriades JA, Ziganshin BA. Practical tips in aortic surgery: Clinical and technical insights. Springer. 2021: 151]) This is like a single-sided "Legs" technique developed by Mills[15].

MODIFICATIONS

Piehler and Pluth[10] described in 1981 the first modification of the classic Cabrol technique. This approach was used by the authors in 5 cases, all with limited mobility of the supraannular aorta for direct reimplantation of the coronary ostium onto the aortic conduit. Short interposition polytetrafluoroethylene grafts were used between the coronary ostium and the aortic graft (Figure 5). It has been debated whether this technique was a modification of the classic Bentall or of the Cabrol technique.[11] While Maureira et al[12] and Hirasawa et al[13] categorized this as a modified Bentall technique, Kourliouros et al[14], Mills et al[15] and Ziganshin et al[11] referred to it as a modification of the classic Cabrol technique. In this review, all coronary reimplantation techniques that require an interposition graft will be classified as modified Cabrol technique (Table 1).

Alternative Interposition Graft Options

In 1996 Mills et al[15] reported the use of a Cabrol modification technique called the "Legs" technique in ten patients. An 8-mm collagen-impregnated knitted Dacron graft was anastomosed on each coronary ostium, then transected, and finally anastomosed onto the aortic conduit (Figure 6). Advantages of the "Legs" technique-specifically reduced risk of kinking, thrombosis, graft compression, and atherosclerosis-compared to the classic Cabrol approach, were reported by the authors.

Table 1. Reports on modified Cabrol procedure

Source	Year	No. of patients with the procedure	Technique
Piehler et al[10]	1981	5	Interposition Gore-Tex graft
Mills et al[15]	1996	10	"Legs" technique
Kourliouros et al[16]	2011	1	-Gore-Tex anastomosis from valve conduit to right coronary ostium -T-graft anastomosis to the left mainstem
Cheng et al[17]	2018	6	-Main graft with one or more branches -Coronary ostium-side branch anastomosis -Use of interposition graft when direct anastomosis is not feasible

CABG, coronary artery bypass graft

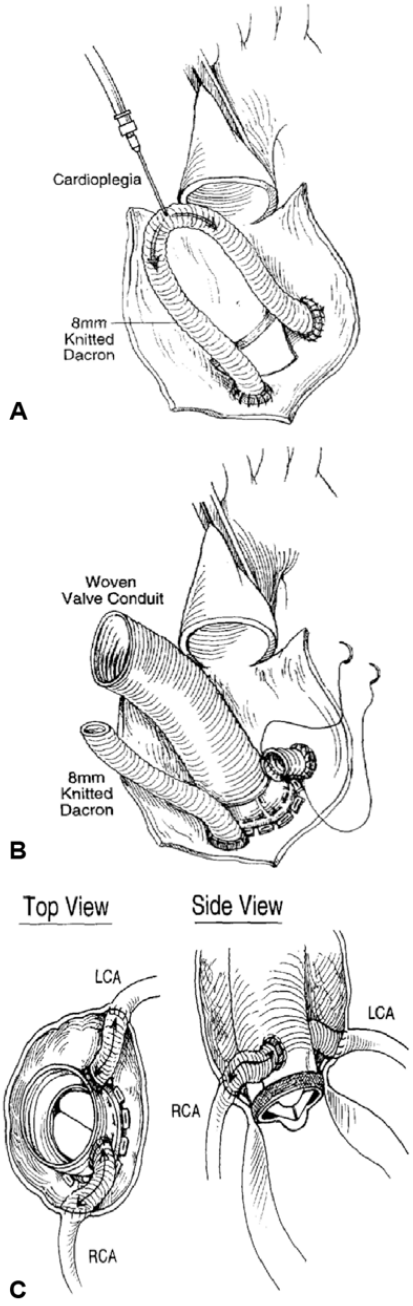

Figure 6. "Legs" technique. The interposition graft is (**A**) anastomosed on each coronary ostium, (**B**) transected, (**C**) anastomosed onto the aortic graft (Reprinted with permission from Mills et al.[15])

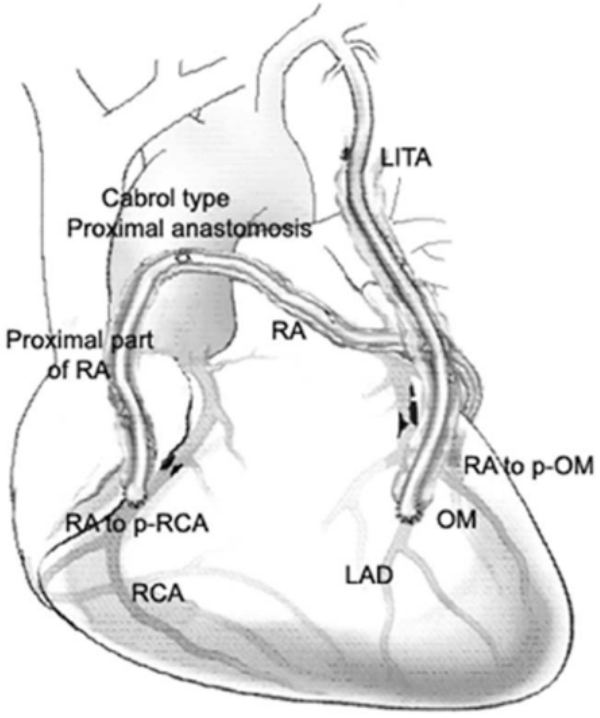

Figure 7. Coronary reimplantation using a radial artery graft in the setting of an off-pump CABG (Reprinted with permission from Jo et al[16]).

In additional work, in 2011 Kourliouros et al[16] documented the use of the modified Cabrol technique in a patient with bicuspid valve aortopathy. An 8-mm polytetrafluoroethylene conduit was used, which was anastomosed onto a 23-mm valved conduit and the right coronary ostium. The graft of the left mainstem was anastomosed in a T-fashion end-to-side onto the right aortocoronary Gore-Tex conduit (Figure 8).

Recently, Cheng et al[17] reported a new coronary reimplantation alternative in a complex reoperative setting. This was performed in 6 patients, all of them reoperative cases, of whom 3 were done for acute Stanford type A aortic dissection. A main graft with one or more branches was used. When a direct anastomosis between the coronary ostium and the side branch was not feasible, a 6 to 8 mm interposition graft was anastomosed to the coronary ostium and the branch of the root graft (Figure 9).

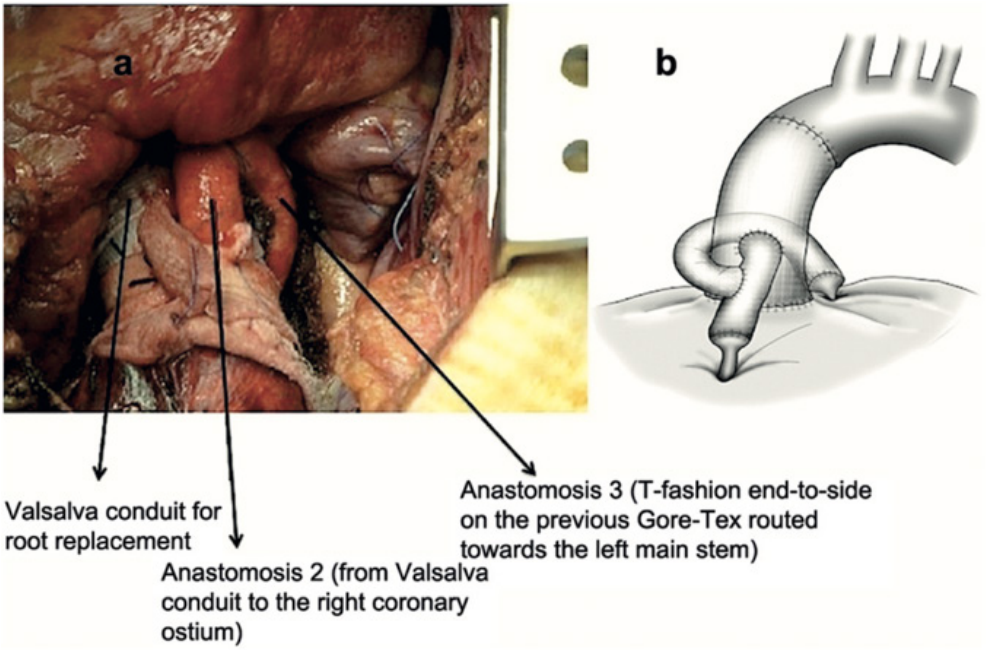

Figure 8. Using a Gore-Tex conduit for coronary reattachment (**a**) Intraoperative view (**b**) Schematic representation. (Reprinted with permission from Kourliouros et al.[17]) See text and labeling on photograph for details.

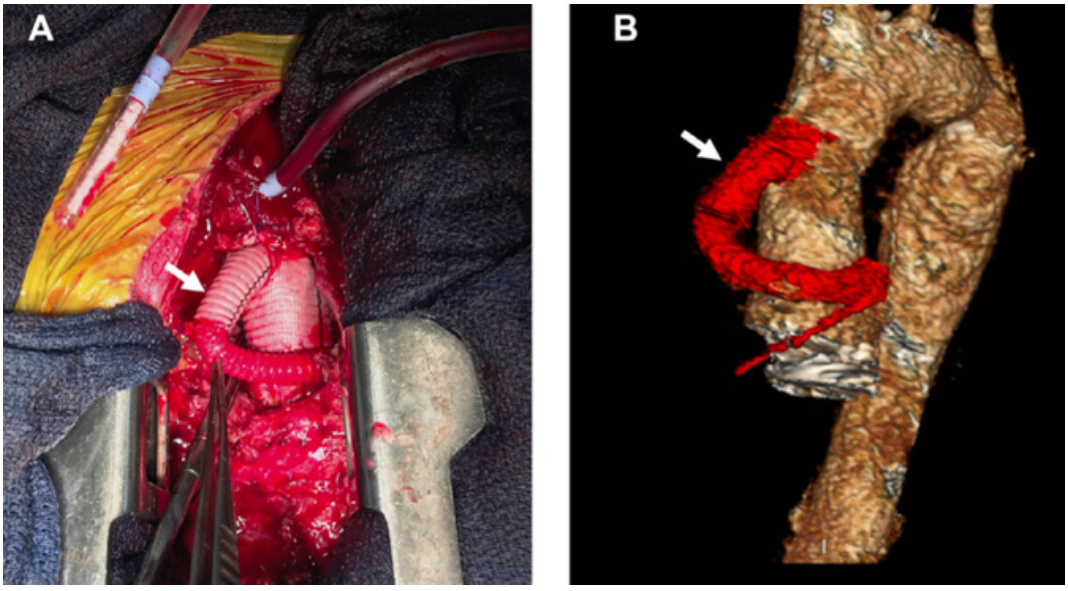

Figure 9. Use of a side branch graft for coronary reimplantation. (**A**) Intraoperative view (**B**) Radiology imaging**.** (Reprinted with permission from Cheng et al.[18]).

OUTCOMES

Multiple studies have documented the outcomes of patients who underwent either a classic or modified Cabrol technique (Table 2). Some of these studies included cases where coronary reimplantation was performed via the classic Bentall or the "button-technique" without using an interposition graft. In such studies, the outcomes related to the different techniques were grouped together. An early mortality between 0 to 41%, and a late mortality between 2.8 to 39% were reported in studies of cases performed with the original, classic Cabrol technique These widely varying (and at times very high) mortality rates reflect different eras of surgery and different acuities of presentation (including extremely acutely and critically ill patients). (Figure 10). On the other hand, the early mortality was between 2.8 to 10.4%, while the late mortality fluctuated between 1.4 to 16.8%, in studies of cases performed with a modified Cabrol procedure.

Among all the patients who underwent a Cabrol procedure in the studies included in Table 2, eight patients (0.8%) developed complications related to the Cabrol graft. These complications included graft thrombosis or occlusion and anastomotic pseudoaneurysm

Table 2. Reports on the outcomes of coronary reimplantation using an interposition graft

Source	Year	N (% Cabrol procedure)	Cabrol Technique		Early Mortality		Late Mortality		Survival Rate, %	Graft Complications, %
			Classic	Modified	N	%	N	%		
Cabrol et al[18]	1986	100	X		4	4	11	12	75 at 8 yrs	0
Svensson et al[19]	1992	348 (45)	X		13	8	__	__	76 at 3 yrs	1,3 RCA occlusion
Lund et al[20]	1993	17	X		7	41	0	0	100 at 3 yrs	5.9 Right limb graft occlusion
Jault et al[21]	1993	339 (77)	X		26[a]	7.6[a]	70[a]	22.4[a]	60 at 9 yrs[a]	0
Aoyagi et al[22]	1994	66 (20)	X		7[a]	10.6[a]	12[a]	20.3[a]	59 at 15 yrs[a]	0
Midulla et al[23]	1994	140 (30)	X		6	20	14[a]	10.5[a]	52 at 5 yrs	0
Bachet et al[24]	1996	203 (13)	X		15[a]	7.3[a]	30[a]	18.4[a]	58 at 8 yrs	3.8 Graft thrombosis
Gelsomino et al[25]	2003	45	X		9	20	6	16.6	59 at 16 yrs	2.2 LCA graft limb occlusion
Hirasawa et al[13]	2006	71		X	3	4.2	1	1.4	94 at 5 yrs	0
Garlicki et al[26]	2006	25	X (24%)	X (76%)	0	0	2	8	__	0
Jault et al[27]	2006	77 (45)	X		8[a]	10.4[a]	27	39[a]	42 at 12 yrs[a]	__
Kitamura et al[28]	2011	36	X		1	2.8	7	20	73 at 10 yrs	5.5 RCA ostium occlusion (2.77) RCA ostium stenosis (2.77)
Maureira et al[12]	2012	153		X	13	8.5	23	16.8	74 at 10 yrs	0.6 Anastomosis pseudoaneurysm
Ziganshin et al[11]	2013	40		X	3	7.5	6	16.2	73 at 6 yrs	0
Mok et al[29]	2017	449 (10)		X	14[a]	3.1[a]	52[a]	12[a]	82 at 10 yrs[a]	0

[a], results for the overall sample; RCA, right coronary artery; LCA, left main coronary artery.

Recently, the Yale Aortic Institute reported outcomes following composite graft aortic root replacement in 449 patients operated by a single surgeon over a 25-year period[30]. All patients underwent a modified Bentall-de Bono procedure with coronary button reimplantation and in 45 patients a modified cabrol procedure (Dacron coronary graft) was used. Operative mortality in the last 10 years was 2.2%. and freedom from reoperation on the aortic root was 97.9% at 20 years (Figure 11). In addition, patients aged less than 60 years had a long-term survival at 20 years of 79.8%, not substantially different from an age and gender matched normal population. This data reflects the low surgical risk, excellent long-term survival, and low incidence of reoperation following composite graft aortic root replacement.

Acute Myocardial Ischemia Management in the Operating Room

Coronary-related complications after aortic composite graft replacement are an uncommon but lethal condition. Ischemia related to coronary button reimplantation must be suspected in any case of severe arrythmia, difficulty in separating from the CPB, pump failure, and intra-operative echocardiographic evidence of regional wall motion abnormalities. Button related ischemia is a technical complication that may be caused by kinking or axial rotation of the coronary buttons after their extensive mobilization (Figure 12). At the same time, too little mobilization of the buttons can produce graft tension (too short), thus compromising coronary blood flow. Our recommendation is that during the anastomosis of the coronary buttons, they should only be mobilized enough to reach the aortic composite graft. With excess mobilization, the now "naked" unsupported proximal coronary vessel is bereft of its normal attachments to surrounding tissues and liable to kinking, torsional, or stretching misadventures. Furthermore, to preserve the anatomic position between the button and the aortic graft, it is recommended to mark each coronary button at the 12 o'clock position[31] (Figure 13). In cases where a direct coronary button anastomosis is not feasible or comfortable, a graft-based Cabrol anastomosis is extremely useful and often life-saving.

The Yale Aortic Institute has documented the utility of "Rescue CABG" surgery immediately after aortic root replacement in patients with suspected acute myocardial ischemia[31,32]. A 5-year survival rate of 100% was reported in those who underwent this surgical procedure[31]. Furthermore, it was identified that non-obstructive coronary calcification of the right or left main coronary artery predisposes to angulation of the coronary button after its anastomosis, with the calcium deposit serving as a fulcrum for angulation[32].

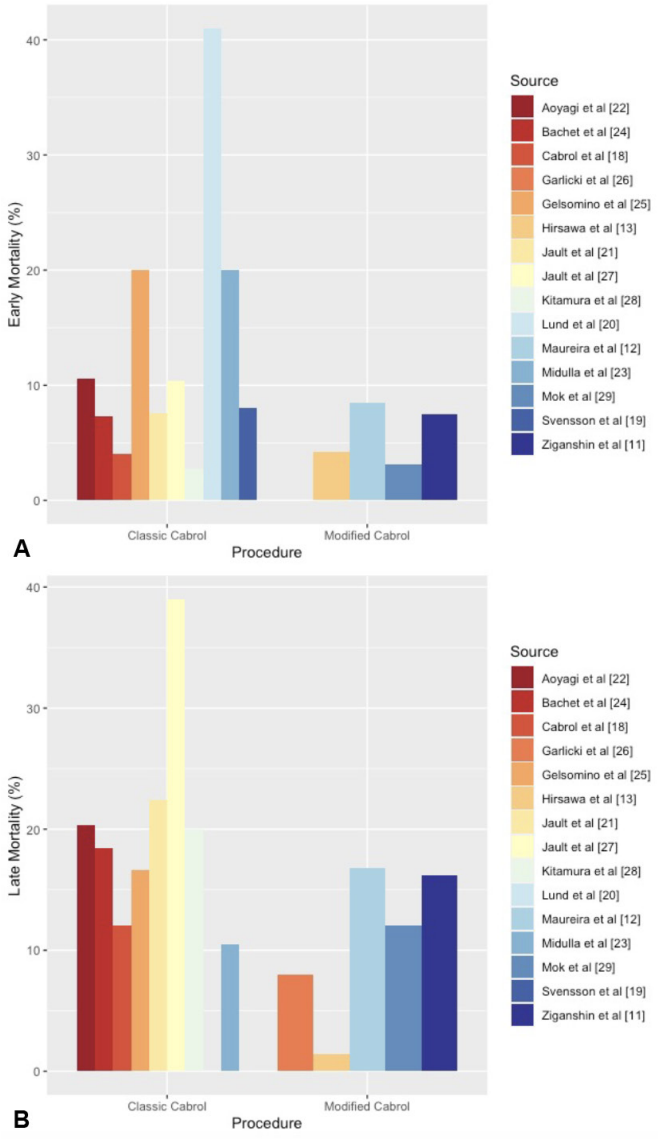

Figure 10. Clinical outcomes of using an interposition graft for coronary reimplantation. (**A**) Early mortality (**B**) Late mortality (**C**) Survival rate. C, classic Cabrol technique; M, modified Cabrol technique.

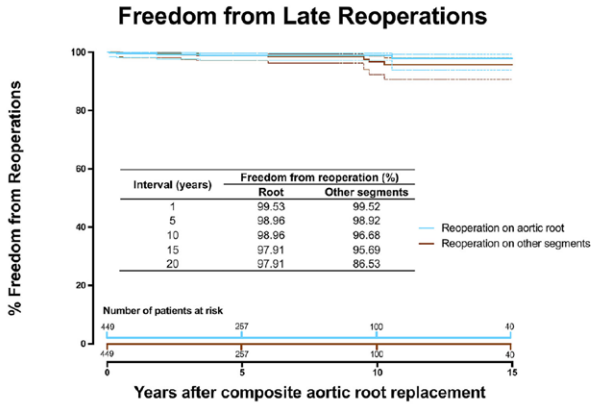

Figure 11. Freedom of reoperation on the aortic root and on other segments. At 10 years the freedom of reoperation on the aortic root was 99% (Reprinted with permission from Mok et al[30])

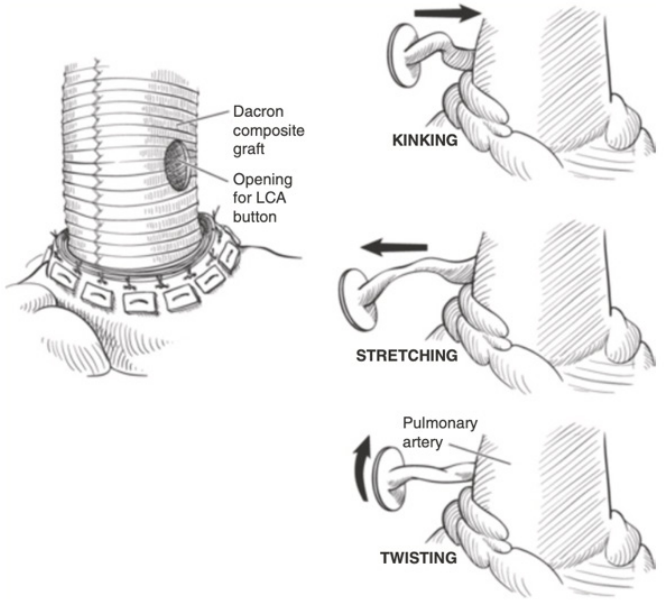

Figure 12. Kinking, stretching, and twisting of the coronary artery after coronary button attachment into the Dacron graft (Reprinted with permission from Shahriari et al[31])

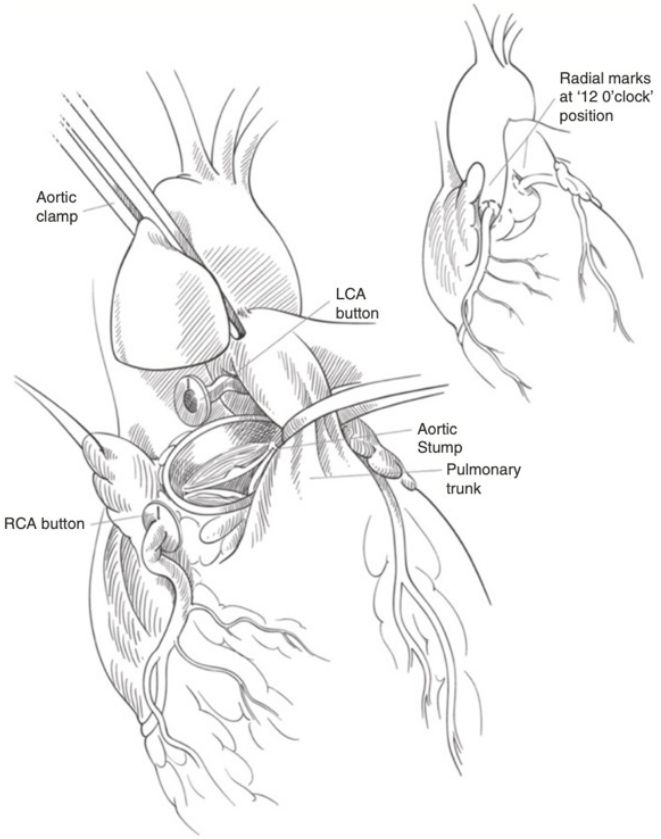

Figure 13. Mobilization of the coronary buttons at the 12 o'clock position (Reprinted with permission from Shahriari et al[31])

CONCLUSION

It has been four decades since the report of the classic Cabrol procedure. During this time, several substantive modifications to this technical procedure have been developed. Also, in the

last two decades, multiple studies have provided evidence on the durability and safety of various Cabrol modifications. These modifications, all graft based, are not recommended routinely, but for anatomic situations in which direct coronary button reattachment is not feasible.

Currently, the most widely used coronary reimplantation method is the "button-technique" described by Kouchoukos and Karp[3] (Figure 1). The exceptionally brief paper by Bentall and DeBono, first describing complete replacement of the aortic root, changed cardiac surgery forever-providing for the first time the ability surgically to replace the aortic root in its entirely, including the root, the ascending aorta, and the coronary ostia. Countless patients have benefitted since that time. The procedure pioneered by Bentall and DeBono and modified by Kouchoukos has proven durable in many long-term studies. This story serves as a vivid example of technical ingenuity leading to long-term saving of life. The Cabrol graft, the precise topic of this review, has served as an ingenious modification of the original composite graft procedure, which has been life-saving in its own right.

Note: Two aortic related procedures carry the "Cabrol" name. The coronary procedure, which is the topic of this paper, should be distinguished from the completely different "Cabrol shunt", which involves using a patch to divert perigraft bleeding into the right atrium.

Conflict of Interest Statement: Dr. Elefteriades: Principal of Coolspine. All other authors report no conflict of interest relative to this work.

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