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Cabrol Procedure in Complex Aortic Root Reconstruction: A Case Series of Three Young Patients With Acute Aortic Syndrome

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ABSTRACT

Acute aortic dissection is a rare but life-threatening syndrome, being accompanied by a mortality rate of 1%–2% per hour after the onset of symptoms if they remain untreated. The definitive therapy for type A acute aortic dissection is considered to be emergency surgery. However, the optimal method for aortic root reconstruction has been a controversial issue. This study presents three cases of acute thoracic aortic dissection (TAD) accompanied by complicated aortic root anatomy. These critical conditions were managed successfully with the Cabrol procedure. In this procedure, the coronary ostia are anastomosed to a second graft in an end-to-end fashion, which is then connected side to side with the ascending aorta. A 2-year follow-up of patients showed they had no new signs or symptoms or reemergence of them during this period. Follow-up transthoracic echocardiography (TTE) and computed tomography angiography (CTA) of the aorta showed no evidence of obstruction or complications of Cabrol and aortocoronary anastomosis. Although the modified Bentall procedure using coronary ostial aortic "buttons" may produce superior results and currently represents the standard of care for aortic root reconstruction, the Cabrol procedure can be considered a clinically valuable rescue procedure in patients whose management becomes more complicated due to anatomic difficulties.

1 | Introduction

Acute aortic syndromes (AAS) include acute aortic dissection, penetrating atherosclerotic aortic ulcer (PAU), and aortic intramural hematoma (IMH). Aortic dissection is responsible for 80%–90% of AAS cases, with minimal disruption that can result in a dissection plane in the media. These dissections may propagate anterograde or, less commonly, retrograde throughout the length of the aorta [1]. There are two major classification schemes for aortic dissection: The DeBakey classification and the Stanford classification. The Stanford classification divides dissections into two types, type A and type B. Type A involves the ascending aorta (DeBakey types I and II), and type B does not (DeBakey type III). Involvement of the ascending aorta and/or arch (Stanford type A) warrants immediate surgical repair [2]. Acute aortic dissection is a rare but life-threatening condition with a mortality rate of 1%–2% per hour after the onset of symptoms if left untreated [3]. Therefore, a prompt and precise diagnosis of acute aortic dissection is a crucial first step to managing the condition successfully to improve the outcomes by increasing the survival rate and declining or preventing serious complications [4].

Abbreviations: AI, aortic insufficiency; CT, computed tomography; IMH, penetrating atherosclerotic aortic ulcer; LMCA, left main coronary artery; LVEF, left ventricle ejection fraction; LVH, left ventricle hypertrophy; PAU, intramural hematoma; RCA, right coronary artery; TAA, thoracic aortic aneurysm; TAD, thoracic aortic dissection; TCA, total circulatory arrest; TEE, transesophageal echocardiography; TTEs, transthoracic echocardiograms.

Summary

- The permanency of coronary ostial anastomosis is an important predictor of morbidity in aortic surgery.
- The advantage of the Cabrol is its ability to reconstruct a tension-free and safe anastomosis of the coronary artery ostia to the aortic conduit.

Acute aortic dissection management includes medical therapies and immediate surgical interventions [2]. Medical therapy to control pain and hypertension is essential in all patients and should be initiated immediately, simultaneously with performing diagnostic tests. Emergency surgery is the definitive therapy for type A acute dissection in patients who are considered appropriate candidates for surgical management [5]. The modified Bentall procedure using coronary ostial aortic "buttons" may improve the results and currently represents the standard of care for aortic root reconstruction PEVuZE5vdGU [6]. The Cabrol procedure has been used less frequently as an alternative to the original Bentall technique. However, in the reports of these three cases, Cabrol surgery following acute aortic dissection was performed and, interestingly, none of the patients had complications during the first 30 months of follow-up.

2 | Case Presentations

2.1 | Case 1

Case history/examination: A 34-year-old woman with a known case of Marfan syndrome with ascending thoracic aortic aneurysm (TAA) was referred to our hospital with severe persistent chest pain radiating to her left arm and interscapular area in September 2021. She had undergone two TTEs 2 years and 6 months ago, and the diameters of the ascending aorta were ~4.8 and 4.9 cm, respectively. Her medical history was positive for hypothyroidism, and she had an episode of acute chest pain 7 months ago that was managed conservatively. She had a negative family history of cardiovascular disease and did not use any drugs.

Method: The transthoracic echocardiogram in the emergency department showed a left ventricle ejection fraction (LVEF) of 50%, a tricuspid aortic valve with severe aortic insufficiency (AI), as well as an intimal flap in the ascending aorta and aortic arch. Computed tomography angiography (CTA) revealed an aneurysmal ascending aorta with a diameter of 5.7 cm, and an aortic intimal flap was seen in the ascending aorta, aortic arch, descending aorta, and abdominal aorta with extension to the proximal part of the bilateral common iliac artery. Considering the observed critical condition, the patient was transferred to the operating room immediately. An arterial

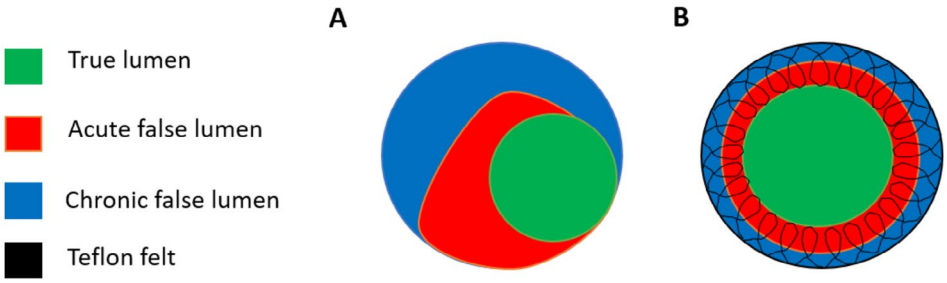

FIGURE 1 | Transverse section of the ascending aorta in our first case. (A) One true lumen, two acute false lumens, and chronic false lumen in the ascending aorta. (B) False lumens were obliterated using the double sandwich technique, employing a strip of Teflon felt.

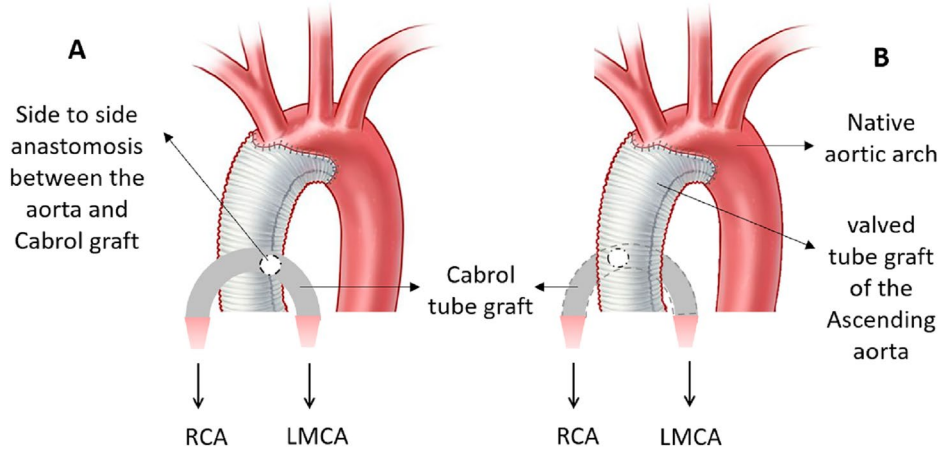

FIGURE 2 | Cabrol procedure. (A) The Classic Cabrol procedure was performed for cases 1 and 2, in which the Cabrol tube graft was connected to the medial and left side of the ascending aorta tube graft. (B) for case 3, the modified Cabrol procedure was carried out, and the Cabrol tube graft was anastomosed to the lateral and right side of the ascending aorta tube graft. LMCA stands for left main coronary artery, and RCA stands for right coronary artery.

cannula through the right femoral artery and a venous cannula in the right atrial auricle were placed; then, a vent was inserted in the left ventricle, and cooling was initiated to lower the core temperature to 27°C. The ascending aorta was carefully examined. Unexpectedly, the surgeon discovered evidence of acute on chronic aortic dissection, with two false lumens (including one with a thickened fixed intimal flap and the second with an acute thinner intimal flap) and a true lumen observed in the ascending aorta (Figure 1). Adequate coronary button harvesting was impossible due to tissue adhesion secondary to previous chronic aortic dissection. Thus, the surgeon decided to perform the Bentall and traditional Cabrol procedures to create a tension-free aortocoronary anastomosis (Figure 2). An 8-mm diameter woven Dacron graft was anastomosed side-to-side to the medial side of the ascending aorta composite graft and end-to-end to the orifices of the left main coronary artery (LMCA) and right coronary artery (RCA). False lumens were obliterated using the double sandwich technique with a strip of Teflon felt (Figure 1).

Conclusion and result: Fortunately, she recovered well and was discharged 1 week later without complications. Clinical follow-up and TTE over the next 2.5 years were satisfying, and the CTA of the aorta 6 and 18 months later showed patent Cabrol anastomosis without any evidence of tube graft kinking or obstruction.

2.2 | Case 2

Case history/examination: A 41-year-old man was referred to the tertiary cardiac emergency center with complaints of sudden retrosternal chest pain, nausea, and vomiting in September 2021. He noted taking amlodipine (5 mg) and losartan (25 mg) once daily due to a previously diagnosed hypertension. His heart rate was 110 beats per minute (bpm), and his blood pressure was 220/120 mmHg in the left arm and 200/115 mmHg in the right arm. The arterial pulse of the right lower limb was weak. Intravenous labetalol infusion started to control his high blood pressure and elevated heart rate.

Method: In addition, TTE in the emergency department showed a normal left ventricle (LV) size with preserved systolic function (LVEF: 50%) and moderate left ventricular hypertrophy (LVH). Moreover, a tricuspid aortic valve with severe AI secondary to a protruding aortic intimal flap to LV and a dilated ascending aorta (size: 4.3 cm), along with an intimal flap, could be seen through it. Thoracic and abdominal CTA revealed an intimal flap in the aortic root with extension to bilateral external iliac arteries. The patient was transferred to the OR to undergo surgical repair. A median sternotomy was performed, and total cardiopulmonary bypass was established by a venous cannula through the right atrium and arterial return cannulas inside the right femoral artery. The aortic intimal flap was extended to the proximal of the aortic arch, and the right coronary artery ostium was also lacerated; thus, the surgeon performed the Bentall procedure with the Cabrol procedure and hemi arch replacement using total circulatory arrest (TCA) for the lower body and antegrade cerebral protection (right carotid artery perfusion:10 cc/kg/min) with 20 min deep hypothermic circulatory arrest (core temperature of 22°C) for the upper body. The second arterial cannula was added to the femoral cannula with a Y tube and snared on the proximal innominate artery. The subclavian and proximal left carotid arteries were closed to prevent cerebral backflow. The distal anastomosis of the ascending aorta conduit was done using the French Cuff technique for better hemostasis. The standard medial side aorta–Cabrol anastomosis with a 10-mm knitted tube graft was performed with proper tube graft angulation and geometry to avoid tube graft obstruction and to maintain a safe patent aortocoronary anastomosis (Figure 2).

Conclusion and result: A week later, the patient developed a high-grade fever despite receiving IV antibiotics (Ceftriaxone 1 g BID and vancomycin 1 g BID). The TTE and Transesophageal echocardiography (TEE) showed no evidence of intracardiac vegetation or abscess formation around the mechanical valve and prosthetic tube grafts (Figure 3 and Video S1) The culture of the sternotomy wound secretion was positive for *Enterobacter*. Previous antibiotics were changed to intravenous amikacin 500 mg BD and cefepime 1 g TDS according to an infectious disease specialist consultation and based on antibiotic susceptibility testing of wound secretion culture. The patient's condition was stabilized after 3 weeks, and he remained afebrile for 4 days before discharge. The patient was asymptomatic during clinical follow-up. Coronary arteries and Cabrol anastomosis were patent on follow-up CTA of the thoracic aorta and coronary arteries performed at 18 and 35 months after the procedure (Figure 3).

2.3 | Case 3

Case history/examination: A 38-year-old woman with a feeling of severe sharp pain in the chest, neck, and throat was referred to the tertiary cardiac emergency center with a provisional diagnosis of AAS in March 2022. She was a known case of Marfan syndrome and had a history of thoracic and abdominal aortic surgery with prolonged post-operation intubation and tracheostomy 7 years ago. Her brother and father expired due to aortic disease at the ages of 35 and 39, respectively. On physical examination, she had severe kyphosis and scoliosis; in addition, scars from left posterolateral thoracotomy and tracheostomy were seen. The patient's blood pressure measurement showed a significant difference between the left (120/60 mmHg) and right (85/50 mmHg) arms.

Method: The initial TTE demonstrated preserved systolic left ventricle function (LVEF: 50%), moderate mitral regurgitation (MR), moderate tricuspid regurgitation (TR), and tricuspid aortic valve with severe AI. Her CTA of the aorta confirmed the diagnosis of AAS. She had a huge, dissected ascending aorta with significant coronary ostium displacement and friable coronary button tissue; therefore, the patient underwent surgery with placement of a St. Jude valve conduit (Bentall operation), hemi arch replacement, and modified lateral Cabrol procedure. An arterial cannula was placed in the right axillary artery using an 8-mm Sillotube graft (Dacron knitted preclotted), and a venous cannula was inserted in the right atrium. Hemi arch replacement was performed using antegrade cerebral protection and 20 min' deep hypothermic circulatory arrest with a core temperature of 22°C. The aortic root was severely dilated, and the

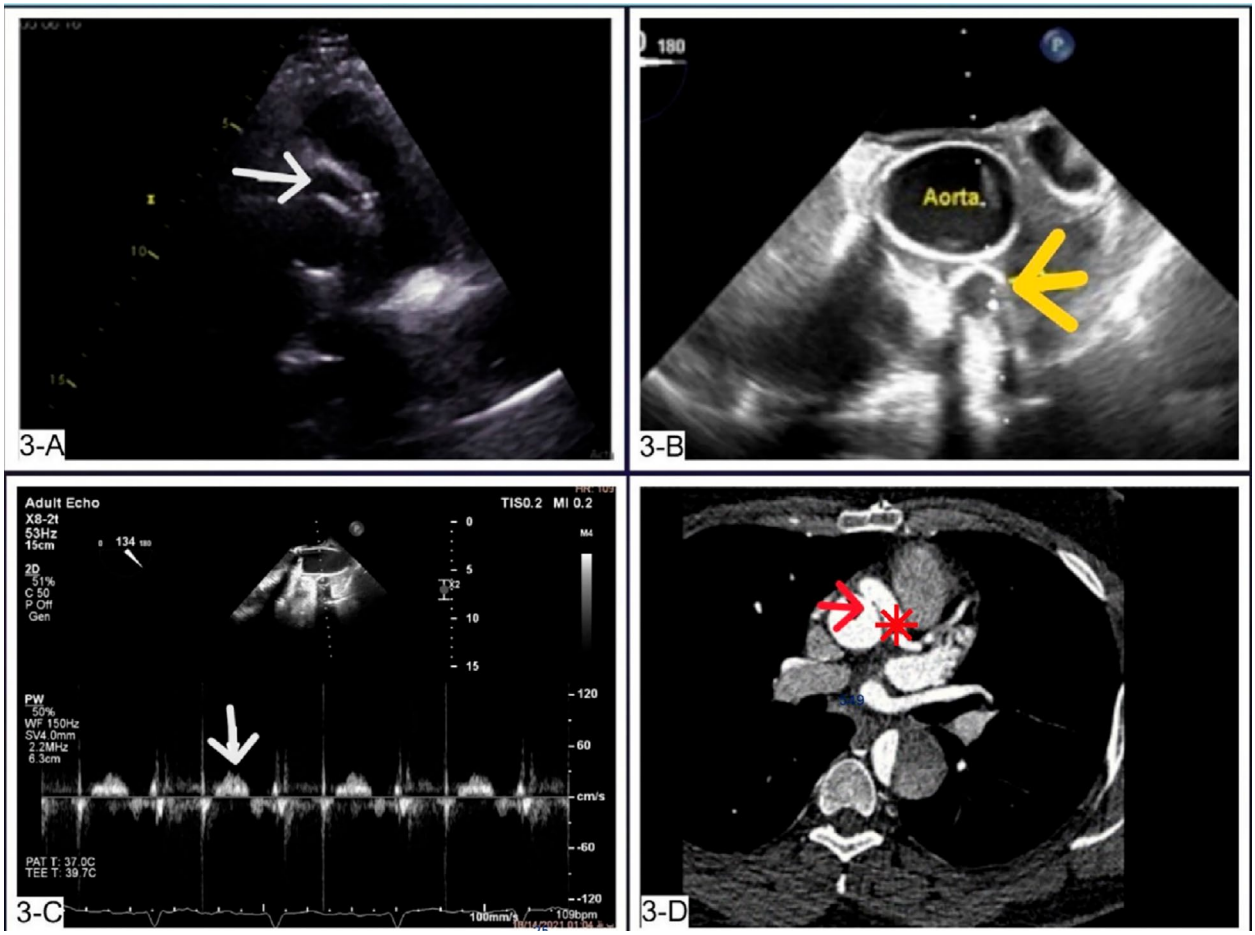

FIGURE 3 | (A) Cabrol tube on the transthoracic short axis parasternal view (white arrow), (B) transesophageal echocardiography shows a textured tube graft (Cabrol anastomosis) in the anterior side of the ascending aorta (yellow arrow). (C) Doppler image of coronary diastolic flow (white arrow) through the cabrol tube graft on the transesophageal echocardiography. (D) Coronary CT angiography performed 35 months post-surgery reveals a patent Cabrol anastomosis to the ascending aorta conduit (red arrowhead), a patent Cabrol to the left main coronary artery connection (red asterisk), and patent coronary arteries.

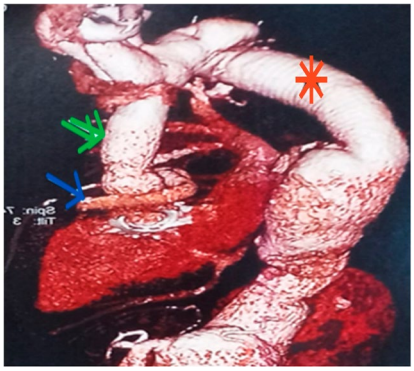

FIGURE 4 | CT angiography of the Aorta reveals modified Cabrol tube graft (blue arrow), tube graft of Bentall procedure in ascending aorta position, hemiarch replacement (green arrows), and previous descending thoracic aorta tube graft (red asterisk).

aortic annulus was significantly fragile; thus, it was reinforced with a Teflon felt washer (a thin circular felt plate with a center hole the same size as the diameter of the sewing ring placed between the annulus and the composite sewing ring) for better buttressing and leakage prevention. The ring of the composite aortic valve graft was anastomosed to the aortic annulus with pledged interrupted mattress sutures. The coronary ostia were anastomosed to the lateral side of the ascending aortic conduit (modified lateral Cabrol procedure) with interposition of a 10-mm knitted preclotted tube graft (Figure 2).

Conclusion and result: due to the high risk of postoperative bleeding, the surgeon closed the patient's sternum the day after the procedure to ensure complete hemostasis has been established. Intravenous vancomycin and meropenem were then initiated. She was discharged after 8 days with stable health status and no complaints. During 2.5 years of clinical follow-up, she had no relevant signs or symptoms. The TTE and CTA showed no evidence of aortocoronary anastomosis obstruction (Figure 4).

3 | Discussion

Based on population studies, the annual occurrence rate of AAS is estimated to range from 2.6 to 7.7 cases per 100,000 person-years. However, in middle-aged individuals, the incidence is much higher, with an estimated rate of 15 cases per 100,000

person-years [7]. Approximately 75% of dissections occur in 40–70-year-old patients, with a peak age of 50–65. Type A aortic dissection occurs most commonly in individuals between 50 and 60 years of age, and type B dissection at a peak of 60–70. Aortic dilatation is a well-established risk factor for thoracic aortic dissection (TAD) but is not a prerequisite; most ascending aortic dissections occur when the aortic diameter is < 5.5 cm [8].

Compared to medical therapy, emergent surgical treatment is associated with improved survival in patients with acute type A aortic dissection [9]. The most frequently performed surgical procedures for aortic root aneurysms and aortic dissection involve replacing the aortic root with a composite valved graft or opting for a valve-sparing root replacement [10]. Valve-sparing aortic root replacement includes aortic root remodeling reported by Sir Magdi Yacoub, reimplantation developed by Tirone David in 1989, and the Florida sleeve introduced by Hess et al. in 2004 [11, 12]. Limited data are also available on the endovascular treatment of ascending aorta dissection, with only small case series or case reports currently published [13]. Ghoreishi, M. et al. presented a case report on endovascular treatment (Endo-Bentall) of aortic root pathologies for high-risk patients with acute type A dissection [14]. In patients who are candidates for surgery, the optimal method for safe reimplantation of coronary arteries on the valved conduits has been a matter of debate [15, 16]. Although the modified Bentall procedure with the use of coronary ostial aortic "buttons" may produce superior results and currently represents the standard of care for aortic root reconstruction, anatomic difficulties (such as the closeness of the Ostia to the aortic annulus, extreme aortic dilatation/calcification, and reoperations) may prevent the safe and tension-free conduit for the coronary anastomosis [17, 18]. The Cabrol procedure was first described by Cabrol et al. in 1981 [9, 19]. The initial Cabrol procedure involves coronary ostia anastomosis to a second graft in an end-to-end fashion, which is then anastomosed to the ascending aortic conduit side-to-side [20].

The Cabrol procedure effectively prevents the formation of pseudoaneurysms in coronary ostia [19]. It serves as a valuable rescue procedure in special cases, such as severe aortic calcification, difficult mobility of coronary arteries, coronary ostia positioned < 1.5 cm above the annulus, previous root surgery resulting in dense fibrotic tissue or pseudoaneurysm formation near the coronary ostium, aortic dissection involving the coronary ostia, pathological processes (e.g., endocarditis and inflammation) causing damage to the coronary ostia, previous scentless valve replacement, homograft or Ross procedure requiring aortic root replacement, and large aneurysms, such as those seen in patients with Marfan syndrome [21–23].

While the Cabrol procedure was an improvement over the classic Bentall, it has its specific complications and has not been widely used as a first-line treatment [24]. Ischemic complications often appear within 5 years after the operation and have been reported up to 14 years later. Cabrol graft kinking, angulation with coronary ostia obstruction, and graft thrombosis/stenosis are the most important complications of the Cabrol technique. Occlusion of the right coronary artery is more common and may be related to non-laminar spiral flow [25].

In a review article, Yang et al. evaluated the effectiveness and long-term outcomes of the Cabrol procedure and its modification. They found that the Cabrol procedure demonstrated an acceptable mortality rate, reoperation rate, anticoagulation outcomes, valve-related complications, and especially Cabrol-related coronary graft complications [24]. The all-cause early mortality was 9.0%, and the 10-year cumulative late mortality was 36.3%. The Cabrol-related coronary graft complications were 0.58% per patient-year. It is worth noting that most Cabrol procedures were performed in reoperations and complex cases [24].

As described above, the Cabrol procedure was used for our patients due to their complicated ascending aorta and aortic root anatomy. During about 2.5 years of follow-up after aortic surgery by clinical assessment, aortic CTA, and TTE, the health status of the patients has been satisfactory, with no evidence of Cabrol to aorta or Cabrol to coronary anastomosis complications. In our patients, we created two perpendicular ovoid punch holes on the Cabrol tube graft and the aortic conduit (Figure 5). Subsequently, we sewed these two incisions together to perform a side-to-side anastomosis, aiming to ensure the patency of the anastomosis site. We tried to do our best to provide ideal Cabrol geometry. We took great care to avoid any kinking or angulation at the anastomosis sites and any tortuosity and redundancy along the Cabrol path to the native coronary ostial. It seems that this procedure has been lifesaving for these particular young patients. Considering that most cardiovascular surgeons underuse the Cabrol procedure, the description and report of these patients and their follow-up can be enlightening for using this technique

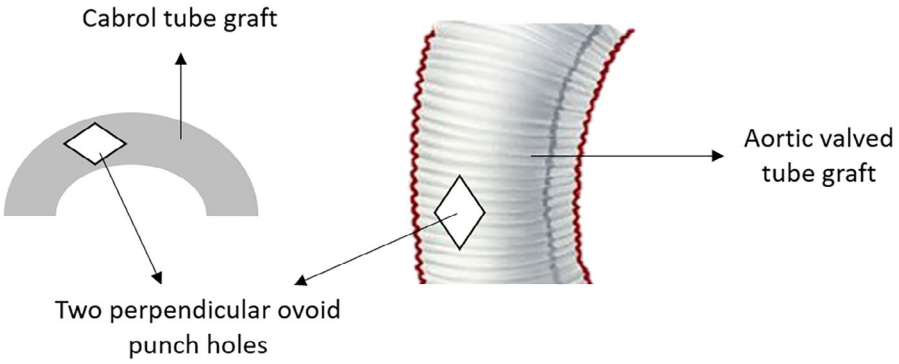

FIGURE 5 | We created two perpendicular ovoid punch holes on the Cabrol graft tube and the aortic conduit and then sewed these two incisions together.

in selected patients and under complicated circumstances. The advantage of the Cabrol procedure is its ability to reconstruct a tension-free and safe anastomosis of the coronary artery ostia to the aortic conduit tube graft when conventional coronary reimplantation techniques fail to provide it. The Cabrol procedure remains a valuable and lifesaving technique, especially when challenging coronary artery mobiliz.

Author Contributions

Yousef Torfi Alaivi: conceptualization. **Seyed Mohammad Hassan Adel:** writing – review and editing. **Amanollah Heidari:** writing – review and editing. **Nehzat Akiash:** data curation. **Fateme Jorfi:** writing – original draft.

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Ethics Statement

Written informed consent was obtained from all three patients to publish this report in accordance with the journal's patient consent policy.

Consent

Written informed consent was obtained from all the three patients to publish this report in accordance with the journal's patient consent policy.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this case series are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.