Percutaneous cardioplegic arrest before repeat sternotomy in patients with retrosternal aortic aneurysm

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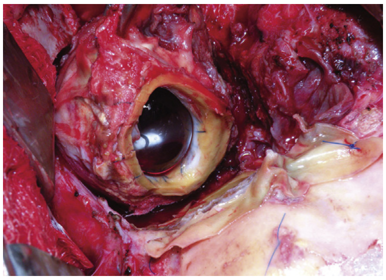
ABSTRACT

Objective: Redo sternotomy in patients with arterial cardiac structures adherent to the sternum carries a risk of catastrophic bleeding. In some of those cases, particularly if they have undergone multiple previous operations, deep hypothermic circulatory arrest alone may not provide sufficient time for a controlled dissection.

Methods: We present a series of 6 cases at risk for exsanguination during sternal re-entry successfully reoperated using percutaneous cardioplegic cardiac arrest induced before completed sternal re-entry to avoid or minimize the hypothermic circulatory arrest time.

Results: All patients survived their complex operations.

Conclusions: Percutaneous cardioplegic arrest allows safer repeat sternotomy in patients with arterial cardiac structures adherent to the sternum. (J Thorac Cardiovasc Surg 2021;161:1724-30)



Inflated endoaortic balloon placed via femoral artery occluding the ascending aorta.

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CENTRAL MESSAGE

Percutaneous cardioplegic arrest allows safe repeat sternotomy in patients with arterial cardiac structures adherent to the sternum.

PERSPECTIVE

Redo sternotomy with cardiac structures adherent to the sternum pose a challenge to cardiac surgeons. We present a series of 6 cases that were successfully reoperated using percutaneous retrograde cardioplegia catheter and endoaortic balloon.

See Commentaries on pages 1731 and 1732.

ADULT

The ascending aorta in direct contact with the sternum after previous operations presents a high risk for catastrophic bleeding with repeat sternotomy. The routine strategy to evade this complication is the initiation of peripheral cardiopulmonary bypass (CPB) and hypothermic circulatory arrest (HCA) before sternotomy, but this strategy is not always effective and sufficient.[1]

We present a recent case series of a strategy in which percutaneous antegrade and retrograde cardioplegic arrest was achieved before completed sternal re-entry in selected cases when sawing into the aorta or a pseudoaneurysm and massive hemorrhages seemed unavoidable. Computed

Scanning this QR code will take you to the table of contents to access supplementary information.

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass
CSCC = coronary sinus cardioplegia catheter
CT = computed tomography
HCA = hypothermic circulatory arrest
OR = operating room
TEE = transesophageal echocardiography

tomography (CT) scan with contrast was obtained in all cases. All cases were performed in the hybrid operating rooms (ORs) to confirm positioning of the catheters and contrast dye was used if needed. This strategy completely avoids or minimizes the needed HCA time. We first used and described this strategy in 2004.[2] It has since been refined, and we are now presenting a current series of 6 cases (the previously published case is not included, details listed in Table 1). Since each case is unique, they are presented as a case series.

Case 1

A 33-year-old male patient with a history of 5 previous sternotomies presented with heart failure secondary to severe mitral regurgitation, an aorta to right ventricular outflow tract fistula, and right ventricular failure. He had a history of commissurotomy for critical aortic stenosis as a neonate, aortic valve replacement with root augmentation, and septal myectomy at age 2 years complicated by severe aortic regurgitation requiring a redo aortic valve replacement with a mechanical prosthesis. Postoperatively, he developed severe mitral regurgitation and underwent patch repair of an anterior mitral leaflet perforation. At age 13 years, he had another aortic valve replacement with root enlargement. He now presented 19 years later with severe mitral regurgitation, a retrosternal aortic aneurysm along with an aorto-right ventricular outflow tract fistula, atrial fibrillation, and hemolytic jaundice. CT of the chest showed the dilated aortic root adherent to the posterior sternum (Figure 1). Patient developed heparin-induced thrombocytopenia after the catheterization and surgery had to be postponed until after his antibody titers against platelet

ADULT

TABLE 1. Details of the patients

	Age/sex	Concurrent medical conditions	No. previous surgeries	Previous operations	Present pathology	Adherent structure
1	33/M	Atrial fibrillation, heparin-induced thrombocytopenia	5	1. Aortic valve commissurotomy 2. AVR, aortic root augmentation, septal myectomy 3. AVR 4. MVR 5. AVR, aortic root augmentation	MR, pseudoaneurysm of the ascending aorta, aorto–RV outflow tract fistula	Pseudoaneurysm of the aortic root
2	60/M	Atrial fibrillation	4	1. ASD repair 2. AVR 3. Ascending aortic aneurysm repair 4. AVR	Severe MR, aortic pseudoaneurysm	Pseudoaneurysm of the ascending aorta
3	29/M	Noonan syndrome, pectus deformity, scoliosis	1	1. AVR (homograft), pulmonary valve commissurotomy	Severe AI (homograft)	Ascending aorta
4	56/M	Endocarditis, CHF, anasarca	4	1. Aortic valve commissurotomy 2. AVR (homograft), MVR 3. AVR (homograft stenosis), MVR 4. Root replacement, MVR	Aortic pseudoaneurysm, severe tricuspid regurgitation, paraprosthetic leak in the mitral and aortic positions	Pseudoaneurysm of the ascending aorta
5	30/M	Intravenous drug abuse, endocarditis	1	1. AVR	Prosthetic valve endocarditis, aortic root abscess	Pseudoaneurysm of the ascending aorta
6	71/F	Endocarditis	2	1. AVR 2. AVR, MVR, TVR	Aortic root abscess	Pseudoaneurysm of the ascending aorta

M, Male; *AVR*, aortic valve replacement; *MVR*, mitral valve replacement; *MR*, mitral regurgitation; *RV*, right ventricle; *ASD*, atrial septal defect; *AI*, aortic insufficiency; *CHF*, congestive heart failure; *F*, female; *TVR*, tricuspid valve replacement.

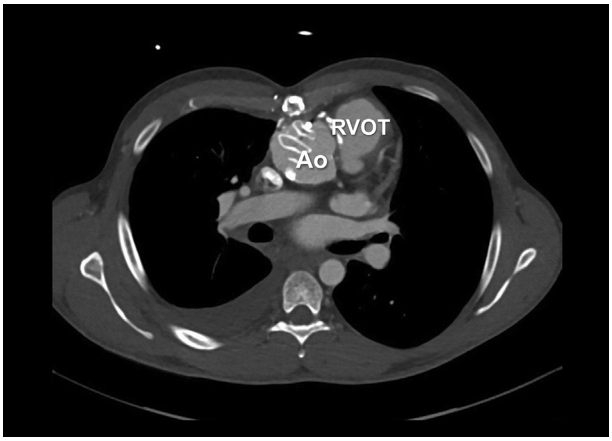

FIGURE 1. Aortic root aneurysm adherent to the sternum with the AMPLATZER device only partially occluding the fistula between the aorta and the pulmonary artery. *RVOT*, Right ventricular outflow tract; *Ao, aorta*.

factor 4 were negative (which took 10 months), and he was scheduled for the sixth time reoperation to replace the mitral valve and ascending aorta including repair of the aorta to right ventricular outflow tract fistula and a maze procedure.

Case 2

This 60-year-old man had a surgical history of 4 heart operations, including atrial septal defect repair, 2 aortic valve replacements, and ascending aorta and hemi-arch aneurysm repair with supracoronary graft. He now presented with severe mitral regurgitation due to bileaflet prolapse and a large ascending aorta pseudoaneurysm originating from the proximal suture line of his ascending aortic graft (Figure 2). He was scheduled for a fifth reoperation, sternotomy for repair of the ascending aorta pseudoaneurysm and aortic valve and root and mitral valve replacement.

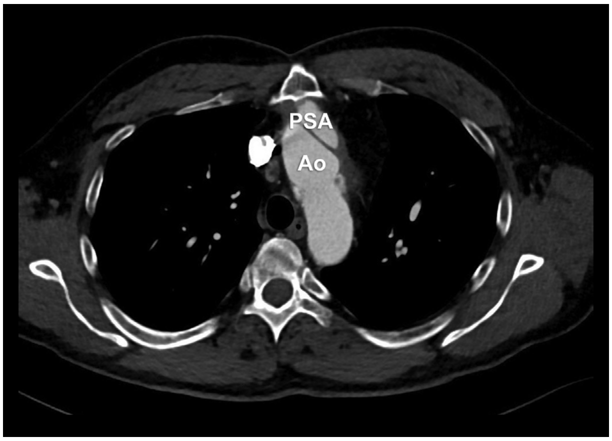

FIGURE 2. Pseudoaneurysm from the proximal suture line of the ascending aortic graft in close proximity to the sternum. *PsA*, Pseudoaneurysm; *Ao*, aorta.

FIGURE 3. Ascending aorta immediately behind the sternum. *Ao*, Aorta.

Preoperatively, CT of the chest showed the aortic pseudoaneurysm adherent to the sternum.

Case 3

A 29-year-old male patient with Noonan syndrome and a history of homograft aortic root replacement (15 mm) and valvotomy for pulmonary stenosis was referred with severe aortic regurgitation for reoperation and aortic valve replacement. His echocardiogram revealed severe homograft regurgitation but preserved biventricular systolic function. CT scan of the chest was notable for a pectus deformity, scoliosis, circumferential calcification of the homograft, and the ascending aorta firmly adherent to the sternum (Figure 3).

Case 4

This 56-year-old man had a history of 3 previous operations including aortic valve commissurotomy, aortic and mitral valve replacement for native valve endocarditis, and another ascending aorta, aortic, and mitral replacement for prosthetic valve endocarditis. He now presented with severe heart failure and anasarca. Echocardiogram revealed severe paraprosthetic regurgitation around the mitral prosthesis and severe tricuspid valve regurgitation. Left ventricular function was preserved, but right ventricular function was moderately decreased. CT confirmed a large pseudoaneurysm originating from the distal suture line of the previous aortic graft (Figure 4).

Case 5

A 30-year-old man with a history of intravenous drug use and aortic valve replacement, followed by a redo sternotomy homograft root replacement 6 months later for endocarditis, presented with back pain and fevers. The echocardiogram revealed that he had dehiscence of the aortic homograft and had a root abscess and severe aortic valve insufficiency. CT scan showed a large pseudoaneurysm immediately behind the sternum (Figure 5).

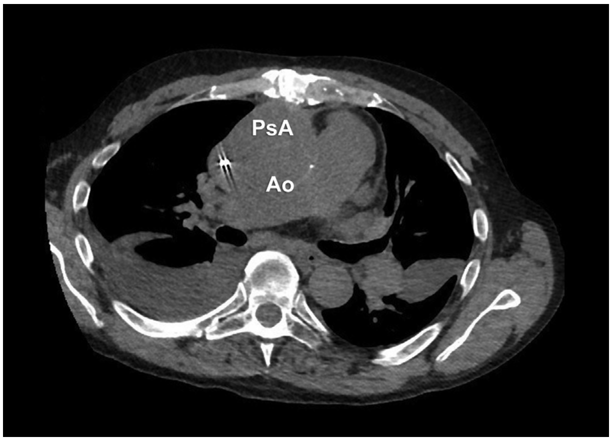

FIGURE 4. Pseudoaneurysm from the distal suture line of the previous aortic graft adherent to the sternum. *PsA*, Pseudoaneurysm; *Ao*, aorta.

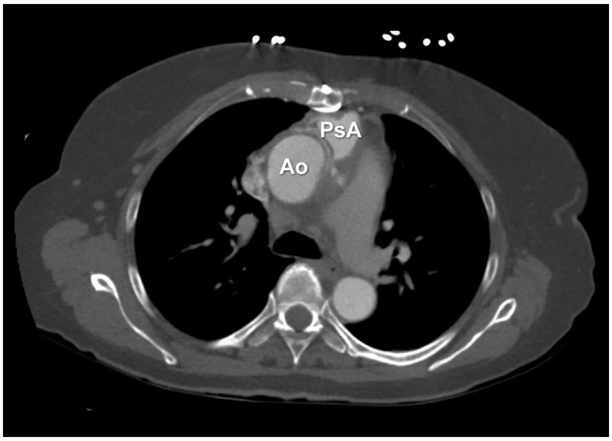

FIGURE 6. Large aortic root pseudoaneurysm extending behind the sternum. *PsA*, Pseudoaneurysm; *Ao*, aorta.

Case 6

This 71-year-old woman had a history of aortic valve replacement and reoperation with aortic root replacement, mitral valve repair, and tricuspid valve repair. She presented with fevers and night sweats, and her blood cultures were positive for methicillin-resistant *Staphylococcus aureus*. Transesophageal echocardiogram (TEE) and a CT scan revealed a large aortic root pseudoaneurysm extending behind the sternum (Figure 6).

Approach

These operations were all performed in a hybrid OR. On arrival to the OR, large-bore peripheral intravenous access was obtained with left brachial artery cannulation for invasive blood pressure monitoring. After successful induction of general anesthesia, central venous access was obtained with a 9-F introducer in the internal jugular vein.

A percutaneous pulmonary artery catheter vent was placed under TEE guidance in cases 1, 3, and 5. In cases 2, 4, and 6, only a pulmonary artery catheter was placed.

In all cases, a retrograde coronary sinus cardioplegia catheter (CSCC) was placed percutaneously under TEE guidance (Figure 7, Video 1).[3] The desired positioning in the coronary sinus was confirmed with fluoroscopy. The placement of the coronary sinus catheter was challenging in case 2, as significant acoustic shadowing by the mechanical mitral valve obscured TEE views in multiple windows. Following placement, increased inflation pressure of the CSCC balloon was noted. Contrast dye revealed that the

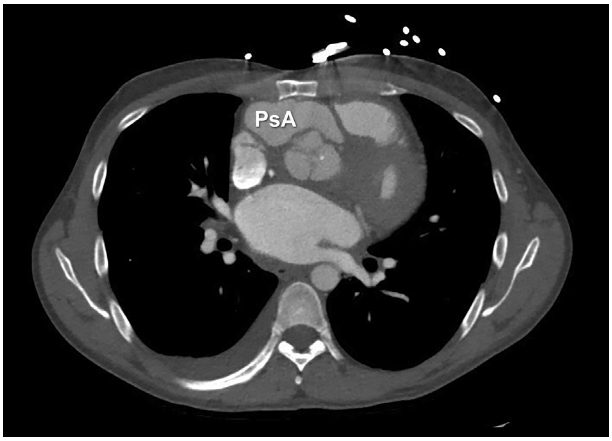

FIGURE 5. Large pseudoaneurysm originating from the posterior aortic root extending behind the sternum. *PsA*, Pseudoaneurysm.

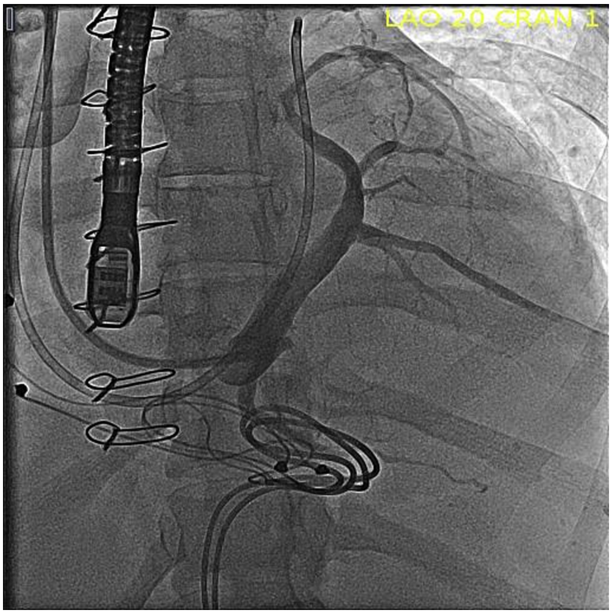

FIGURE 7. Venogram of the coronary sinus to confirm the position of the retrograde coronary sinus catheter.

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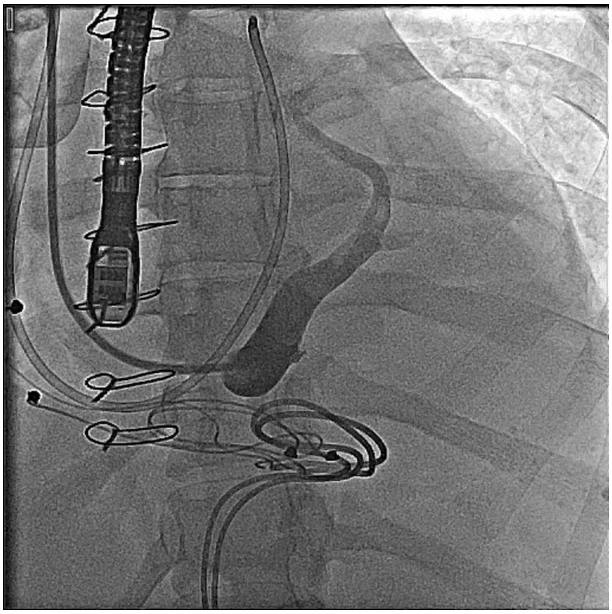

VIDEO 1. Confirming the position of the percutaneous retrograde coronary sinus catheter under fluoroscopy. Video available at: https://www.jtcvs.org/article/S0022-5223(19)33067-3/fulltext.

CSCC was positioned in the great cardiac vein, and this was repositioned.

The right axillary artery and the femoral vessels in both groins were exposed. Next, a partial lower sternotomy was performed to identify the planes and expose as much of the heart as deemed possible and safe from the CT before heparinization and cannulation for CPB. In 2 cases (4 and 5), the incision was T-d off to the right to dissect out the inferior vena cava and right atrium. Both the right axillary artery and left femoral artery were used for inflow arterial cannulation. Venous cannulation was achieved via the exposed inferior vena cava in 4 cases and via the right femoral vein with a long cannula reaching up to the right atrium in 2 cases. Venous cannula placement was aided by the use on TEE. The right femoral artery was cannulated and used to advance the percutaneous endoaortic balloon into the ascending aorta under TEE guidance in 5 cases. In 1 case, extensive scarring prevented the use of the right femoral artery for cannulation, and in this case the left femoral artery was used for both arterial inflow and endoaortic balloon deployment.

After initiation of CPB, cooling was commenced. When the heart fibrillated (at 28°C-30°C), the percutaneous endoaortic balloon was inflated to occlude the ascending aorta (Figure 8) and the heart was arrested with antegrade and retrograde cardioplegia delivered via the endoaortic balloon catheter and the percutaneously placed retrograde cardioplegia catheter.

The sternotomy was completed and in 4 of the 6 cases, 1, 2, 5, and 6, the pseudoaneurysm or aorta was entered. The endoaortic balloon served its purpose as it prevented bleeding and allowed continued systemic perfusion. The aorta was dissected out while systemic circulation and cardiac arrest were maintained and the heart decompressed by the endoaortic balloon and the pulmonary vent. Once the aorta was fully dissected out, the endoaortic balloon was removed and replaced with a regular aortic crossclamp. In cases 3 and 4, the adherent part of the aorta and pseudoaneurysm, respectively, was safely freed from the posterior aspect of the sternum without any injury to adjacent cardiac structures. In case 4, an additional fistula was visualized between the pseudoaneurysm and the SVC. In case 5, the endoaortic balloon was successfully deployed after the heart fibrillated and the heart arrested with antegrade and retrograde cardioplegia. However, ascending aorta distal to the pseudoaneurysm and the endoaortic balloon was injured upon re-entry, requiring short periods of low flow and circulatory arrest until the aorta was dissected out enough to place a regular crossclamp.

OR time and cardiopulmonary bypass times were long in all cases (Table 2). Case 1 required inotropic support and inhaled nitric oxide due to elevated pulmonary artery pressures and moderate to severely decreased right and left ventricular function. Bleeding and coagulopathy were an issue in all cases (Table 3). A rapid infuser was available for large volume transfusions of blood products. A Cabrol patch with fistula to the right atrium was used in cases 1 and 4.

The intended operations were performed and completed in all cases, and all patients left the hospital alive and are alive and functional 20, 21, 15, 9, and 3 months (patients 1 to 4 and 6, respectively) after their operations; patient 5 was discharged alive but lost to follow-up.

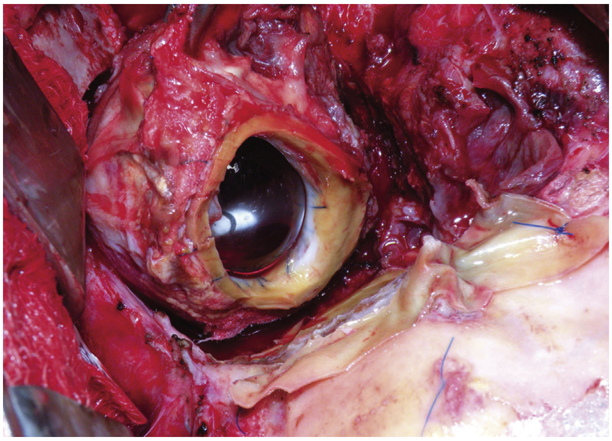

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FIGURE 8. Inflated endoaortic balloon placed from the femoral artery occluding the distal ascending aorta.

DISCUSSION

In cases in which injury to aorta or a pseudoaneurysm has been deemed unavoidable, we have used an alternative

TABLE 2. Duration of CPB, crossclamp, lowest temperature (during opening), and circulatory arrest

Case	CPB, min	Crossclamp time, min	Circulatory arrest, min	Lowest temperature, °C, bladder/blood
1	297	249	9	18.9/16.6
2	246	200	0	25.9/25.1
3	148	123	1	19.6/18.4
4	363	286	25*	19.2/17.5
5	284	219 (182 ± 37)	1	16.6/16.3
6	342	258	0	31.4/31.1

CPB, Cardiopulmonary bypass. *The longer arrest time in case 4 was not for the opening but for an aortic arch anastomosis performed later with deep hypothermic circulatory arrest retrograde cerebral perfusion.

approach in which cardioplegic arrest of the heart was achieved percutaneous before complete sternotomy. This not only creates a bloodless field but also allows continued systemic and cerebral perfusion and avoids or minimizes the use of HCA while the heart is protected with cardioplegia (Video 2).

This case series exemplifies the importance of a systematic, multidisciplinary approach to preoperative planning and perioperative execution. Cardiac imaging, especially CT scan of the chest, is invaluable for the preoperative assessment. Identifying structures adherent to the sternum, the extent of their adhesion, and accessible parts on sternotomy are key components of discussion. Size of the aortic segments and quality of the aorta (wall thickness and calcification) must be considered when percutaneous endoaortic balloon deployment is planned. Similar considerations should be made for peripheral access for cardiopulmonary bypass.

It does take some time to dissect out and obtain control of the aorta and the time available is related to the temperature to which it is possible to cool before the heart fibrillates and the left ventricle becomes distended and the lungs congested.[4] Reoperative interventions with the conventional strategy of peripheral cannulation and low flow or circulatory arrest may not provide enough time for adequate protection of the brain and the heart, particularly if the patient also has important aortic valve regurgitation or a fistula between the aorta and the pulmonary artery preventing cooling to lower temperatures. HCA in the presence of aortic regurgitation requires a left ventricular vent to adequately decompress the ventricle,[2,5] but a vent cannot handle severe aortic regurgitation.

We recognized that due to multiple previous open-heart surgeries and prosthetic valve placements, the cardiac anatomy in the chest would likely be altered and lead to ambiguous TEE views. Standard TEE views may be difficult to obtain in these patients. We strongly endorse use of the hybrid OR to supplement TEE with access to live fluoroscopy for the placement and positioning of port-access percutaneous catheters and cannulas. Proper CSCC positioning is critical because inadequate depth risks dislocation of the catheter with surgical manipulation of the heart and venous cannula placement. In addition, repositioning of the catheter during the procedure, known to be extremely challenging, was not required in any of our cases. Hanada and colleagues[3] suggest advancing the catheter under live fluoroscopy guidance until the tip lies two-thirds to three-fourths of the distance between the coronary sinus ostium and the left border of the heart. This typically involves advancing 4 to 5 cm beyond the ostium of the coronary sinus. Excess depth, in contrast, may compromise protection of the right ventricle, as the middle and small cardiac vein distributions are not being perfused with cardioplegia. TEE was used as the primary imaging modality for CSCC placement. Contrast dye and fluoroscopy was used to confirm the position.

Use of the endoaortic balloon requires careful considerations. Contraindications to endoaortic balloon placement, such as peripheral vascular disease, aortic atheromatous disease, tortuous femoral and/or iliac arteries, aortic aneurysm, and Marfan, Turner, or other syndromes with weaker aortic tissue are to be taken into consideration. Aortic regurgitation is another cited contraindication for the use of the endoaortic balloon. In the present series, however, aortic regurgitation and in one case an aorta to right ventricular

ADULT

TABLE 3. ICU and hospital stay, transfusions, and complications

	ICU stay (d)	Hospital stay (d)	Intraoperative blood transfusion	Complications
1	13	19	Cryo 6 U, FFP 20 U, Plt 6 U, RBC 15 U	Open chest (closure POD 2), prolonged ventilator support, renal failure requiring CVVHD
2	4	9	Plt 2 U	
3	3	8	Cryo 4 U, FFP 1 U, Plt 3 U	
4	15	35	Cryo 65 U, FFP 11 U, Plt 6 U, RBC 13 U	Open chest (closure POD 6), prolonged ventilator support, renal failure without dialysis
5	5	13	Cryo 6 U, FFP 3 U, Plt 4 U, RBC 6 U	Open chest (closure POD 1), prolonged ventilator support
6	9	23	Cryo 4 U, FFP 6 U, Plt 2 U, RBC 7 U	

Definition: prolonged ventilator support (greater than 24 hours), renal failure (creatinine greater than 2.0 mg/dL or 2 times above preoperative baseline or dialysis). *ICU*, Intensive care unit; *Cryo*, cryoprecipitate; *FFP*, fresh-frozen plasma; *Plt*, platelets; *RBC*, red blood cells; *POD*, postoperative day; *CVVHD*, continuous veno-veno hemodialysis.

Preop CT scan

VIDEO 2. Drs Pettersson and Mehta describing case 1, highlighting the importance of preoperative planning and introducing various techniques used to safely perform a reoperation in patients who have arterial cardiac structures adherent to the sternum. Video available at: https://www.jtcvs.org/article/S0022-5223(19)33067-3/fulltext.

fistula were instead indications to use the endoaortic balloon to occlude the proximal aorta and to vent the left ventricle, while the myocardial protection was obtained by systemic cooling, and retrograde cardioplegia.

The ideal endoaortic balloon position is distal to the pseudoaneurysm entry point without obstructing the brachiocephalic trunk, which can be ascertained on the preoperative CT scan. Balloon migration is a serious issue; short migration may cause occlusion of the innominate artery with cerebral hypo- or hyperperfusion dependent on arterial cannulation site. When warmed up in the patient, the endoaortic balloon catheter becomes soft and distal migration/embolization of the catheter to the abdominal aorta is a potential complication (personal experience). To prevent and secure against the consequences of migration, biarterial, axillary and femoral cannulation was used. Proximal endoaortic balloon migration is also an issue to be aware of; the sinus portion of the root is larger than the ascending aorta and pulls the catheter proximally. Proximal migration may jeopardize delivery of antegrade cardioplegia and place the balloon proximal to area at maximum risk of injury during the sternal reentry. Migration can be detected by TEE surveillance, by using bilateral brachial arterial catheters, and by fluoroscopy. The coronary anatomy was normal in all patients and satisfactory myocardial protection was achieved in all cases but was relying more on retrograde delivery through the percutaneously placed retrograde cardioplegia catheter than antegrade delivery through the endoaortic balloon especially in cases with severe aortic regurgitation.

Today we use the hybrid OR for complex re-operative sternotomy cases for which we believe percutaneous cardioplegic arrest before sternotomy is required. The ability to complement TEE with live fluoroscopy in optimal positioning of the CSCC and endoaortic balloon was important, in at least one case critical. In case 2, with TEE alone, the distal positioning of our CSCC would have risked coronary vein rupture and compromised myocardial protection to the right ventricle. Placement and maintaining optimal position of the endoaortic balloon in the ascending aorta is also difficult. TEE and fluoroscopy are essential, and the position must be carefully checked during inflation. Once the sternotomy has been completed, the position can be adjusted in the field after the aorta has been entered. So far, the possible cooling to ≤30°C has always provided enough time to obtain control of the aorta and avoid neurologic complications. (The time the endoaortic balloon was inflated to the aorta was dissected out and a regular crossclamp applied was unfortunately not recorded.)

Percutaneous cardiac arrest before sternal reentry is a novel strategy to avoid catastrophic bleeding from aorta or pseudoaneurysm in immediate proximity of the sternum. This strategy allows adequate myocardial protection and continued brain perfusion, avoiding deep HCA and ischemic neurologic injury. Although the potential benefits are obvious, this strategy is complex, challenging, and demanding and requires the tools, a very well-coordinated team and access to a hybrid OR is certainly an advantage.

Conflict of Interest Statement

Dr Gillinov is a consultant to AtriCure, Medtronic, Edwards Lifesciences, Abbott, CryoLife, Johnson and Johnson, and ClearFlow; he issued a patent for devices for mitral valve repair. All other authors have nothing to disclose with regard to commercial support.

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Key Words: endoaortic balloon, percutaneous cardioplegia, pseudoaneurysm, resternotomy