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Direct reimplantation of left coronary artery into the aorta in adults with anomalous origin of left coronary artery from the pulmonary artery

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Abstract:	Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital anomaly. It represents one of the most common causes of myocardial ischemia and infarction in children and if left untreated, results in a mortality rate of up to 90% within the first year of life. In patients who survive into the adulthood, the coronary steal phenomenon and retrograde left-sided coronary flow provide a substrate for chronic subendocardial ischemia which may lead to left ventricular dysfunction, ischemic mitral regurgitation, malignant ventricular arrhythmias and sudden cardiac death. The average age of life-threatening presentations is 33 years and of sudden cardiac death 31 years. Therefore, surgical correction is highly recommended as soon as the diagnosis is made, regardless of age. In adult-type of ALCAPA originating from the right-handed facing sinus of the pulmonary artery direct reimplantation of the ALCAPA into the Aorta is the more physiological repair technique to reestablish the dual-coronary perfusion system and is to be recommended. This protocol describes the technique of direct reimplantation of adult type ALCAPA into the aorta.
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	Zurich 20. December 2016 Dear Dr. DSouza I would like to submit the re- re-revised version of our work entitled "Direct reimplantation of left coronary artery into the aorta in adults with anomalous origin of left coronary artery from the pulmonary artery" for publication in JOVE. All the requested revisions have been addressed and integrated into the new version in red font to ease the reading. The Table of Materials has been expanded as required. I hope you will find this re- re-revised version of our work suitable for publication in JOVE and am looking forward to hearing from you. Best regards Reza Tavakoli
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TITLE:
Direct reimplantation of left coronary artery into the aorta in adults with anomalous origin of left coronary artery from the pulmonary artery

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KEYWORDS:
Direct reimplantation, anomalous left coronary artery from pulmonary artery, ALCAPA, coronary artery, cardiac surgery, aorta, coronary artery, pulmonary artery.

SHORT ABSTRACT:
Surgical correction of ALCAPA is highly recommended, regardless of age or the degree of intercoronary collateralization. This protocol presents a technique for the direct reimplantation of adult-type ALCAPA into the aorta to re-establish the dual-coronary perfusion. Whenever feasible, direct reimplantation is preferred to other surgical correction techniques.

LONG ABSTRACT:
Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital anomaly which is one of leading causes of myocardial ischemia and infarction in children. If left untreated, it results in a 90% mortality rate in the first year of life. In patients who survive to the adulthood, the coronary steal phenomenon and retrograde left-sided coronary flow provide a substrate for chronic subendocardial ischemia, which may lead to left ventricular dysfunction, ischemic mitral regurgitation, malignant ventricular arrhythmias, and sudden cardiac death. The average age of life-threatening presentation is 33 years and of sudden cardiac death 31 years. Therefore, surgical correction is highly recommended as soon

as the diagnosis is made, regardless of age. In adult-type ALCAPA originating from the right-facing sinus of the pulmonary artery, direct reimplantation of the ALCAPA into the aorta is the more physiologically sound repair technique to re-establish the dual-coronary perfusion system and is recommended. This protocol describes the technique of direct reimplantation of adult-type ALCAPA into the aorta.

INTRODUCTION:
Anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) is a rare congenital anomaly usually seen as an isolated lesion[1]. The incidence of ALCAPA is estimated at 1 in 300,000 live births, comprising between 0.24% and 0.46% of congenital cardiac diseases[2,3]. It is one of the most common causes of myocardial ischemia and infarction in children and, if left untreated, results in a 90% mortality rate in the first year of life[4]. Only 10-15% of infants survive to adulthood due to the rapid development of a large dominant right coronary artery (RCA) with extensive intercoronary collaterals[4]. During the neonatal period, high pulmonary vascular resistance and the resultant pulmonary artery (PA) pressures ensure that antegrade flow in maintained from the PA into the anomalous left coronary artery. As the pulmonary vascular resistance gradually decreases, antegrade flow to the left coronary artery reduces. This eventually leads to reversal of flow, and left-to-right shunting into the PA, thus resulting in a “coronary steal[5].” Thus, left ventricular (LV) myocardial perfusion depends on intercoronary collaterals from an RCA[5,6].

The coronary steal phenomenon and retrograde left-sided coronary flow provide a substrate for chronic subendocardial ischemia, which may lead to left ventricular dysfunction, ischemic mitral regurgitation, and malignant ventricular arrhythmias precipitated by acute myocardial ischemia[7]. In a subset of adult patients, the mean age at presentation is 41 years, with a shift in sex distribution toward female patients (Female-to-male ratio: 2:1)[8]. In this patient population, 14% are asymptomatic; 66% present with symptoms of angina, dyspnea, palpitations, or fatigue; and 17% present with life-threatening symptoms, including ventricular arrhythmias, syncope, and sudden cardiac death[8]. The average age of life-threatening presentation is 33 years and of sudden cardiac death 31 years[8]. Therefore, surgical correction is highly recommended as soon as the diagnosis is made, regardless of age or the degree of intercoronary collateralization[1,9].

Depending on the origin of the anomalous left coronary artery, direct reimplantation of the ALCAPA into the aorta is the more physiologically sound repair technique to reestablish the dual-coronary perfusion system. Most commonly, ALCAPA takes off from the right-hand pulmonary sinus (sinus 1 of the PA), which faces the aortic sinus where the main left coronary artery usually originates (sinus 2 of the aorta)[10]. This coronary anatomy is most suited to the direct reimplantation technique. The aim of this report is to describe, in detail, the technique for the direct reimplantation of the left coronary artery in ALCAPA in adult patients. The rationale behind direct reimplantation is the advantage—the physiological reestablishment of dual-coronary perfusion—it offers over the ligation of the anomalous left coronary combined with coronary artery bypass grafting[11-13].

PROTOCOL:

The protocol follows the institutional guidelines of the human research ethics committee of the University of Zurich.

1. Preparation for surgery

1.1. Clean and prepare the surgical suite in a typical manner. To facilitate communication between the surgeon and the perfusionist, place the heart-lung machine to the left of the patient, opposite to the surgeon.

1.2. Pre-medicate the patient by the oral administration of 5 mg of midazolam, 30-60 min prior to the induction of anesthesia.

1.3. Let the patient be monitored according to standard guidelines, with direct arterial and central venous pressure access by the anesthesiologists. Induce anesthesia using an initial intravenous injection of 0.5-1.5 mg/kg propofol, 1-2 µg/kg fentanyl, and 0.6 mg/kg rocuronium.

1.4. Perform tracheal intubation and maintain the anesthesia through the intravenous infusion of 100-150 µg/kg/min propofol, 0.015-0.03 µg/kg/min fentanyl, and 0.6-1.2 µg/kg/min rocuronium as needed.

1.5. Install the patient in a supine position and drape her/him in a sterile fashion, leaving the chest, the abdomen, and the groin free in the operative field.

2. Surgery

2.1. To minimize crowding of the operative field by cannulas, establish the cardio-pulmonary bypass access outside the thorax.

2.1.1. Perform a 6 cm-long incision 2 cm below and parallel to the right clavicular. Prepare the right subclavian artery, freeing it from the surrounding tissue. Give 300 I.U. of heparin/kg through the IV line.

2.1.2. Side-clamp the right subclavian artery with a Cooley Derra clamp. Perform a 10 mm-long arteriotomy of the vessel parallel to its axis.

2.1.3. Sew an 8-mm Dacron graft end-to-end to the arteriotomy using a running 6/0 polypropylene monofilament suture (*e.g.,* Prolene). Cannulate the graft with a 24 Fr elongated one-piece arterial cannula for arterial return to the patient.

2.1.4. Under transesophageal echocardiographic guidance, cannulate the right femoral vein percutaneously over a guidewire for venous drainage.

2.2. Access the heart through a median sternotomy.

2.2.1. Incise the skin longitudinally over 15 cm, starting 1 cm below the suprasternal notch. Take care to stay in the middle of the sternal width.

2.2.2. Saw the sternum with an oscillatory saw. Take care to stay in the middle of the sternal width.

2.2.3. Incise the pericardium over the aorta to uncover the massively dilated and tortuous right coronary artery.

2.2.3.1. Grab the pericardium with Carpentier dissection forceps. Cut the pericardium with Metzenbaum scissors. Continue cutting the pericardium up to its reflection line over the ascending aorta using electrocautery.

2.2.4. Start the extra-corporeal circulation and dissect the aorta circumferentially, freeing it from the surrounding tissue, including the pulmonary artery, taking care not to injure the anomalous left coronary artery.

2.2.4.1. Gently push the ascending aorta to the left using a lung retractor. Grab the soft tissue behind the ascending aorta with Carpentier dissection forceps.

2.2.4.2. Separate the posterior wall of the ascending aorta from the surrounding tissue using electrocautery. Continue caudally behind the ascending aorta. Make sure not to injure the right pulmonary artery behind the ascending aorta.

2.2.4.3. Grab the main pulmonary artery with Carpentier dissection forceps and push it gently towards the left side. Separate the left lateral wall of the ascending aorta from the main pulmonary artery using electrocautery.

2.2.5. Dissect the main pulmonary artery free from the surrounding tissue.

2.2.5.1. Pull the ascending aorta towards the right side using a peanut gauze mounted on an Allis clamp.

2.2.5.2. Bluntly dissect the posterior wall of the main pulmonary artery with a second peanut gauze mounted on an Allis clamp. Make sure not to injure the main left coronary artery behind the main pulmonary artery.

2.2.5.3. Pass a dissector under the main pulmonary artery. Gently open the dissector to prepare a tunnel for the passage of the vessel loop.

2.2.5.4. Bring down a vessel loop mounted on Carpentier dissection forceps and place it between the open jaws of the dissector. Close the jaws of the dissector to grab the vessel loop.

2.2.5.5. Grab the adventitia of the ascending aorta and pull the vessel loop held by the dissector to encircle the main pulmonary artery.

2.2.6. Place a left ventricular vent.

2.2.6.1. Place a purse-string on the right upper pulmonary vein with a 4/0 polypropylene monofilament suture.

2.2.6.2. Gently push the superior vena cava towards the left side.

2.2.6.3. Make a small cut in the middle of the purse-string on the right upper pulmonary vein with an 18-blade knife (see the table of materials).

2.2.6.4. Gently dilate the opening with a Leriche hemostatic clamp.

2.2.6.5. Insert a vent through the right upper pulmonary vein and the mitral valve into the left ventricle to unload the left heart. Secure it with a braided polyester 2/0 ligature with polybutylene coating.

2.2.7. Place a retrograde cardioplegic cannula through the coronary sinus. Secure it with a braided polyester 2/0 ligature with a polybutylene coating.

2.2.8. Install the antegrade cardioplegic root.

2.2.8.1. Place a purse-string on the main pulmonary artery with a 4/0 polypropylene monofilament suture.

2.2.8.2. Make a small cut in the middle of the purse-string on the main pulmonary artery with an 18-blade knife (see the table of materials).

2.2.8.3. Gently dilate the opening with a Leriche hemostatic clamp. Insert an antegrade cardioplegic cannula in the main pulmonary artery. Secure it with a braided polyester 2/0 ligature with polybutylene coating.

2.2.8.4. Place a purse-string on the ascending aorta with a 4/0 polypropylene monofilament suture.

2.2.8.5. Make a small cut in the middle of the purse-string on the ascending aorta with an 18-blade knife.

2.2.8.6. Gently dilate the opening with a Leriche hemostatic clamp.

2.2.8.7. Insert an antegrade cardioplegic cannula into the ascending aorta. Secure it with a braided polyester 2/0 ligature with polybutylene coating. Cut the ligature with Metzenbaum scissors. Verify the correct placement of the antegrade cardioplegic cannulas in the main pulmonary artery and ascending aorta.

2.3. Prepare to open the aorta.

2.3.1. Cross-clamp the aorta as distally as possible. Deliver the antegrade cold blood cardioplegia simultaneously through the aorta and the pulmonary artery.

2.3.2. Remove the cannulas from the aorta and the pulmonary artery and repeat the cold blood cardioplegia retrogradely every 20 min.

2.3.3. Transect the aorta.

2.3.3.1. Grab the ascending aorta with Carpentier dissection forceps on each side of the opening left following the removal of the cardioplegic cannula. Enlarge the opening with an 18-blade knife.

2.3.3.2. Finish the transection of the aorta with Metzenbaum scissors. Verify the absence of the left coronary ostium inside the aorta in the left sinus of Valsalva.

2.3.4. Transect the main pulmonary artery.

2.3.4.1. Grab the main pulmonary artery with Carpentier dissection forceps on each side of the opening left following the removal of the cardioplegic cannula. Enlarge the opening with an 18-blade knife.

2.3.4.2. Finish the transection of the main pulmonary artery with Metzenbaum scissors. Confirm the presence of the left coronary ostium, originating from the right-facing sinus 1[10] of the pulmonary artery.

2.3.5. Detach the left coronary ostium from the right-facing sinus 1 of the pulmonary artery.

2.3.5.1. Grab the proximal main pulmonary artery with Carpentier dissection forceps. Using Metzenbaum scissors, separate the left coronary ostium from the right-facing sinus 1 of the pulmonary artery with a generous surrounding patch of the pulmonary root wall, taking care not to injure the pulmonary valve.

2.3.5.2. Mobilize the main left coronary artery up to its bifurcation.

2.4. Prepare for the reimplantation of the left coronary ostium.

2.4.1. Grab the proximal ascending aorta with Carpentier dissection forceps.

2.4.2. Use a straight blade to create a neo-ostium in the left sinus 2 of the aorta. Leave a 10-mm margin of aortic root wall around the neo-ostium towards the commissure between the left sinus 2 and the right coronary sinus of the aorta, as well as towards the aortic annulus.

2.4.3. Connect the main left coronary ostium end-to-end to the neo-ostium in the left sinus 2 of the aorta using a running 6/0 polypropylene monofilament suture. Start the anastomosis at the deepest point of the main left coronary ostium and allow it to come up on the right-hand side of the anastomosis. Complete the anastomosis by running the left-hand side of the suture to meet the other end.

2.4.4. To relieve tension on the tissue when pulling the sutures, bring the aorta and the main left coronary ostium together each time.

2.5. Repair the defect in the pulmonary artery root.

2.5.1. Use a non-treated autologous pericardial patch.

2.5.2. Connect the autologous pericardial patch at the deepest point of the right-facing sinus 1 of the pulmonary artery using a running 6/0 polypropylene monofilament suture.

2.5.3. First run up the left and then the right end of the suture to mid-height of the defect in the right-facing sinus 1 of the pulmonary artery. Leave the two ends of the suture under tension.

2.6. Reestablish the continuity of the great vessels.

2.6.1. Reconnect the proximal part of the aorta to its distal part with an end-to-end anastomosis using a running 5/0 polypropylene monofilament suture. Start the anastomosis at the deepest point, allowing it to come up on the right-hand side of the anastomosis. Complete the anastomosis by running the left-hand side of the suture to meet the other end.

2.6.2. De-air the aorta. Remove the aortic cross-clamp. Start rewarming the patient.

2.6.3. To shorten the ischemic time, perform the reconnection of the proximal and distal parts of the pulmonary artery on the beating heart. Put the pump sucker into the distal pulmonary artery to improve the sight of the operative field.

2.6.4. Continue in a running fashion the left end of the 6/0 polypropylene suture that had been stopped at mid-height of the defect in the right-facing sinus 1 of the pulmonary artery to complete the posterior and left aspects of the anastomose.

2.6.5. Continue in a running fashion the right end of the 6/0 polypropylene suture that had been stopped at mid-height of the defect in the right-facing sinus 1 of the pulmonary artery to complete the posterior and right aspects of the anastomose. Tie the two ends of the suture to finish the connection.

REPRESENTATIVE RESULTS:

Presentation

The patient was a 48-year-old woman presenting with the recent onset of angina Canadian Cardiovascular Society (CCS) grad III and occasional palpitations. She reported three uneventful pregnancies. Moderate smoking was the main cardiovascular risk factor. Trans-thoracic echocardiography showed a moderately impaired (45%) left ventricular ejection fraction and no mitral regurgitation. A coronary angiography was then performed. It demonstrated the absence of the left main coronary artery arising from the aorta. The right coronary artery was considerably enlarged and perfused the main left coronary artery via intraseptal collaterals (Figure 1). Thus, the diagnosis of ALCAPA was made. The anatomical type of ALCAPA was further defined by bi-plan (Figure 2) and three-dimensional (Figure 3) CT scans.

Post-operative course
The patient was separated from the cardiopulmonary bypass at a core temperature of 37 °C. No post-operative myocardial ischemia occurred. Bleeding from the chest tube drain was less than 30 mL/h. The patient was weaned from the ventilator and extubated 6 h post-operatively. She was discharged from the intensive care unit to the normal ward on the first post-operative day. Her course on the ward remained uneventful; she was discharged to a cardiac rehabilitation program on post-operative day 9.

One-year follow-up
The patient was seen at the outpatient clinic one year after surgery. She was working full-time and had no angina or dyspnea. Her exercise test was negative. Figure 4 shows her CT scan one year after surgery. The reimplanted ALCAPA is widely patent at the site of anastomosis to the aorta. The pulmonary artery does not present any narrowing at the site of reconstruction with the autologous pericardial patch used to repair the defect in the right-facing sinus of the PA.

FIGURE LEGENDS:

Figure 1: Pre-operative coronary angiography. A) The coronary angiography of the patient is remarkable for the absence of the ostium of the main left coronary artery (LCA) in the aorta. In a right anterior oblique view, the opacified right coronary artery (RCA) is considerably enlarged, measuring 12 mm. It follows a tortuous path across the right heart while supplying large collaterals to the left-sided circulation via intraseptal collateral vessels (yellow arrows). These collaterals feed the left anterior descending (LAD) and left circumflex (CX) arteries, which join the main left coronary artery and drain in a retrograde fashion into the main pulmonary artery (PA). **B**) This diagram shows a schematic representation of the normal distribution of the coronary arteries. (1 mm on figure scale = 2 mm)

Figure 2: Pre-operative computed tomography. A cardiac computed tomography scan shows the take-off of the ALCAPA from the right-facing sinus of the PA according to the Dodge-Khatami classification[10]. (1mm on figure scale = 2.14 mm)

Figure 3: Pre-operative three-dimensional computed tomography. A three-dimensional reconstruction of the computed tomography of the great vessels confirms the topography of the ALCAPA originating from the right-facing sinus 1 of the PA and the RCA from the facing sinus 1 of the aorta[10]. From this anatomy, a direct translocation of the ALCAPA to the aorta seems feasible. (1 mm on figure scale = 1.66 mm)

Figure 4: Follow-up post-operative computed tomography. In the right panel, the computed tomography scan of the patient one year after surgery shows a widely patent main left coronary artery (ALCAPA) connected to the aorta. The reconstructed pulmonary artery (PA) does not present any narrowing. In the left panel, the pre-operative computed tomography depicts the ALCAPA originating from the right-facing sinus of the PA according to the Dodge-Khatami classification[10]. (1 mm on figure scale = 2.14 mm in the left panel, 1 mm on figure scale = 2.5 mm in the right panel)

DISCUSSION:

This protocol describes a detailed technique for the direct reimplantation of the ALCAPA into the aorta in an adult patient with the origin of main left coronary artery from the right-facing sinus of the pulmonary artery according to the Dodge-Khatami classification[10]. The myocardial protection strategy and the reconstruction of the pulmonary artery are clearly demonstrated. The major critical step of this technique is represented by the generous mobilization of the left coronary artery to achieve a tension-free anastomosis.

Prolonged desaturated coronary perfusion is tolerated into adulthood in a small number of individuals. ALCAPA patients who survive to adulthood present with a spectrum of clinical manifestations, ranging from the absence of symptoms to acute myocardial infarction and/or chronic myocardial ischemia[8]. The latter would ultimately lead to left ventricular dysfunction, ischemic mitral regurgitation, malignant ventricular arrhythmias, and sudden cardiac death[7]. Therefore, surgical correction is highly recommended as soon as the diagnosis is made, regardless of age or the degree of intercoronary collateralization[1,9].

In both adults and infants, the direct reimplantation of the ALCAPA represents the physiological repair method and is the preferred technique when the anatomy is suitable[1]**.** However, in adults, the direct reimplantation of the ALCAPA might be more challenging because of a very short main left coronary artery, increased coronary artery friability, diminished vessel elasticity for mobilization, and the potential for tearing and the resultant uncontrollable bleeding[14,15]. In these situations, coronary artery bypass grafting associated with the ligation of the ALCAPA may be more suitable[11-13]. In a series of 30 patients with ALCAPA, 3 of which were adults, Neumann *et al.* performed 19 direct reimplantations, 9 Takeuchi repairs, and 2 ligations[16]. The early and late 24-year survival rates for direct reimplantation were both 100%, and the 10-year rate of freedom from reoperation was 94.1%[16]. At the last follow-up, 95.5% of the patients were in New York Heart Association functional class I[16].

Other options for surgical repair aim to prevent the coronary steal phenomenon and, ideally, to restore dual-coronary circulation. The simplest corrective procedure involves ligating the LMCA, which does prevent steal, but does not allow for antegrade flow into the left-sided circulation. Therefore, this is most often combined with bypass grafting[11,12]. This approach, less physiological than the previous, is generally the most straightforward in adults, but there remains a risk of late graft stenosis, especially with saphenous vein grafts[13]. In adults, creating an intrapulmonary baffle (Takeuchi procedure) is a more complex option that does restore the dual-coronary supply but that may be complicated by supravalvular pulmonary stenosis and baffle obstruction or leakage[13,17].

The treatment of associated ischemic mitral valve regurgitation remains controversial and depends on the degree, as well as the functional versus structural type, of regurgitation. The age of the patient, the personal experience of the surgeon, and the ability of the center must also be considered. In infants, most authors recommend an expectative approach, unless the mitral regurgitation is severe[1,16]. In adults, the decision on the concomitant surgical correction of functional ischemic mitral regurgitation during the operation for ALCAPA should be made with regard to the severity of the mitral regurgitation and the possibility for it to worsen after intra-operative norepinephrine tests. An aggravation of mitral regurgitation following norepinephrine challenge, evidenced by intra-operative transesophageal echocardiography, would support the correction of the mitral regurgitation. For structural mitral regurgitation, correction would be recommended for more than mild regurgitation, unless the prolongation of the cross-clamp time is deemed undesirable for the patient.

In conclusion, in adult-type ALCAPA originating from the right-facing sinus of the pulmonary artery, direct reimplantation into the aorta is recommended, provided that the tissue is of adequate elastic quality. Thickening and calcification of the main left coronary could be detected in the pre-operative computed tomography. However, the final evaluation of the tissue elasticity is performed by intra-operative visual inspection and gentle palpation of the vessel wall for the absence of calcified plaques and by the tactile perception of tissue resistance during mobilization.

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DISCLOSURE:
The authors have nothing to disclose.

REFERENCES:
1. Dodge-Khatami, A., Mavroudis, C. & Backer, C.L. Anomalous origin of the left coronary artery from the pulmonary artery: collective review of surgical therapy. *Ann. Thorac.* Surg. **74** (3), 946 –955 (2002).
2. Keith, J.D. The anomalous origin of the left coronary artery from the pulmonary *artery. Br. Heart J.* **21** (2), 149–161 (1959).
3. Hauser, M. Congenital anomalies of the coronary arteries. *Heart* **91** (9), 1240–1245, doi: 10.1136/hrt.2004.057299 (2005).
4. Wesselhoeft, H., Fawcett, J.S. & Johnson, A.L. Anomalous origin of the left coronary artery from the pulmonary trunk. Its clinical spectrum, pathology, and pathophysiology, based on a review of 140 cases with seven further cases. *Circulation* **38** (2), 403–425 (1968).
5. Edwards, J.E. The direction of blood flow in coronary arteries arising from the pulmonary trunk. *Circulation* **29** (2), 163–166 (1964).
6. Agustsson, M.H., Gasul, B.M., Fell, H., Graettinger, J. S., Bicoff, J. P. & Waterman, D. F. Anomalous origin of the left coronary artery from the pulmonary artery diagnosis and treatment of infantile and adult types. *JAMA.* **180** (1), 15–21 (1962).
7. Roberts, S.M., Banbury, T. & Mehta, A. A rare case of anomalous left coronary artery from the pulmonary artery (Bland-White-Garland Syndrome) in a 68-year-old woman. *Semin. Cardiothorac. Vasc. Anesth.* published online before print July 9, doi: 10.1177/1089253216659146 (2016).
8. Yau, J.M., Singh, R., Halpern, E.J. & Fischman, D. Anomalous origin of the left coronary artery from the pulmonary artery in adults: a comprehensive review of 151 adult cases and a new diagnosis in a 53-year-old woman. *Clin. Cardiol.* **34** (4), 204-210, doi: 10.1002/clc.20848 (2011).
9. Michielon, G. *et al*. Anomalous coronary artery origin from the pulmonary artery: correlation between surgical timing and left ventricular function recovery. *Ann. Thorac. Surg.* **76** (2), 581-588, discussion 588 (2003).

10. Dodge-Khatami, A., Mavroudis, C. & Backer C.L. Congenital Heart Surgery Nomenclature and Database Project: anomalies of the coronary arteries. *Ann. Thorac. Surg.* **69** (4 Suppl), S270-S297 (2000).
11. Talwar, S., Jha, A.J., Choudhary, S.K., Gupta, S.K. & Airan, B. Repair of anomalous left coronary artery from pulmonary artery (ALCAPA) beyond infancy. *Heart Surg. Forum* **16** (4), E210-E215, doi: 10.1532/HSF98.20131008 (2013).
12. Toumpourleka, M., Belitsis, G., Alonso, R., Rubens, M., Moat, N. & Gatzoulis, M. Late presentation and surgical repair of ALCAPA. *Int. J. Cardiol.* **186**, 207-209, doi: 10.1016/j.ijcard.2015.03.202 (2015).
13. Quah, J.X. *et al.* The management of the older adult patient with anomalous left coronary artery from the pulmonary artery syndrome: a presentation of two cases and review of the literature. *Congenit. Heart Dis.* **9** (6), E185-E194, doi: 10.1111/chd.12125 (2014).
14. Kottayil, B.P. *et al*. Anomalous origin of left coronary artery from pulmonary artery in older children and adults: direct aortic implantation. *Ann. Thorac. Surg.* **91** (2), 549-53, doi: 10.1016/j.athoracsur.2010.08.032 (2011).
15. Rajbanshi, B.G., Burkhart, H.M., Schaff, H.V., Daly, R.C., Phillips, S.D. & Dearani, J.A. Surgical strategies for anomalous origin of coronary artery from pulmonary artery in adults. *J. Thorac. Cardiovasc. Surg.* **148** (1), 220-224, doi: 10.1016/j.jtcvs.2013.08.026 (2014).
16. Neumann, A. *et al*. Long-term results after repair of anomalous origin of left coronary artery from the pulmonary artery: Takeuchi repair versus coronary transfer. *Eur. J. Cardio-Thorac. Surg.* Epub ahead of print Sept. 9, doi: 10.1093/ejcts/ezw268 (2016).
17. Peña, E., Nguyen, E.T., Merchant, N. & Dennie, C. ALCAPA syndrome: not just a pediatric disease. *Radiographics* **29** (2), 553-565, doi: 10.1148/rg.292085059 (2009).

Figure 1

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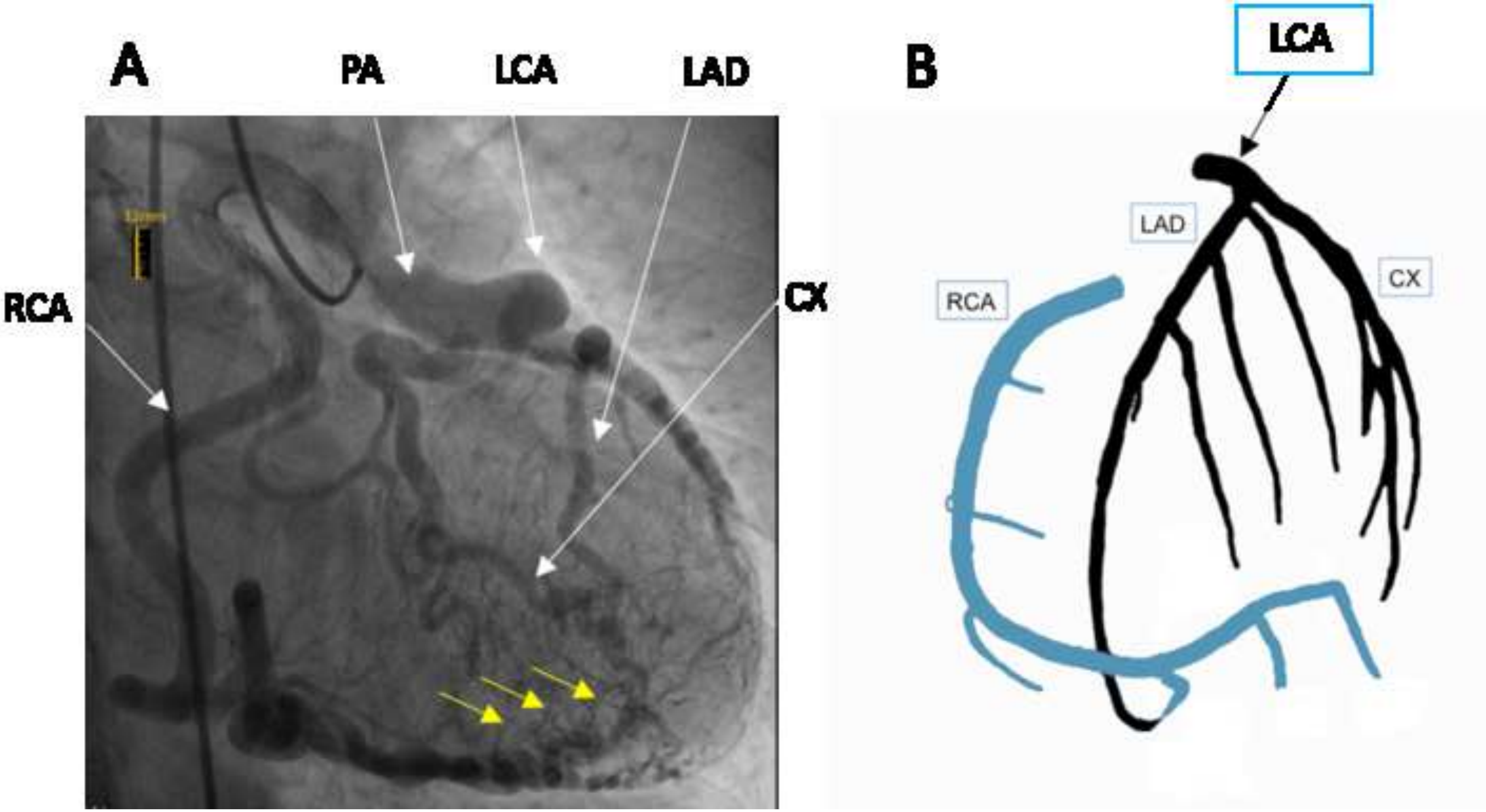

Figure 2

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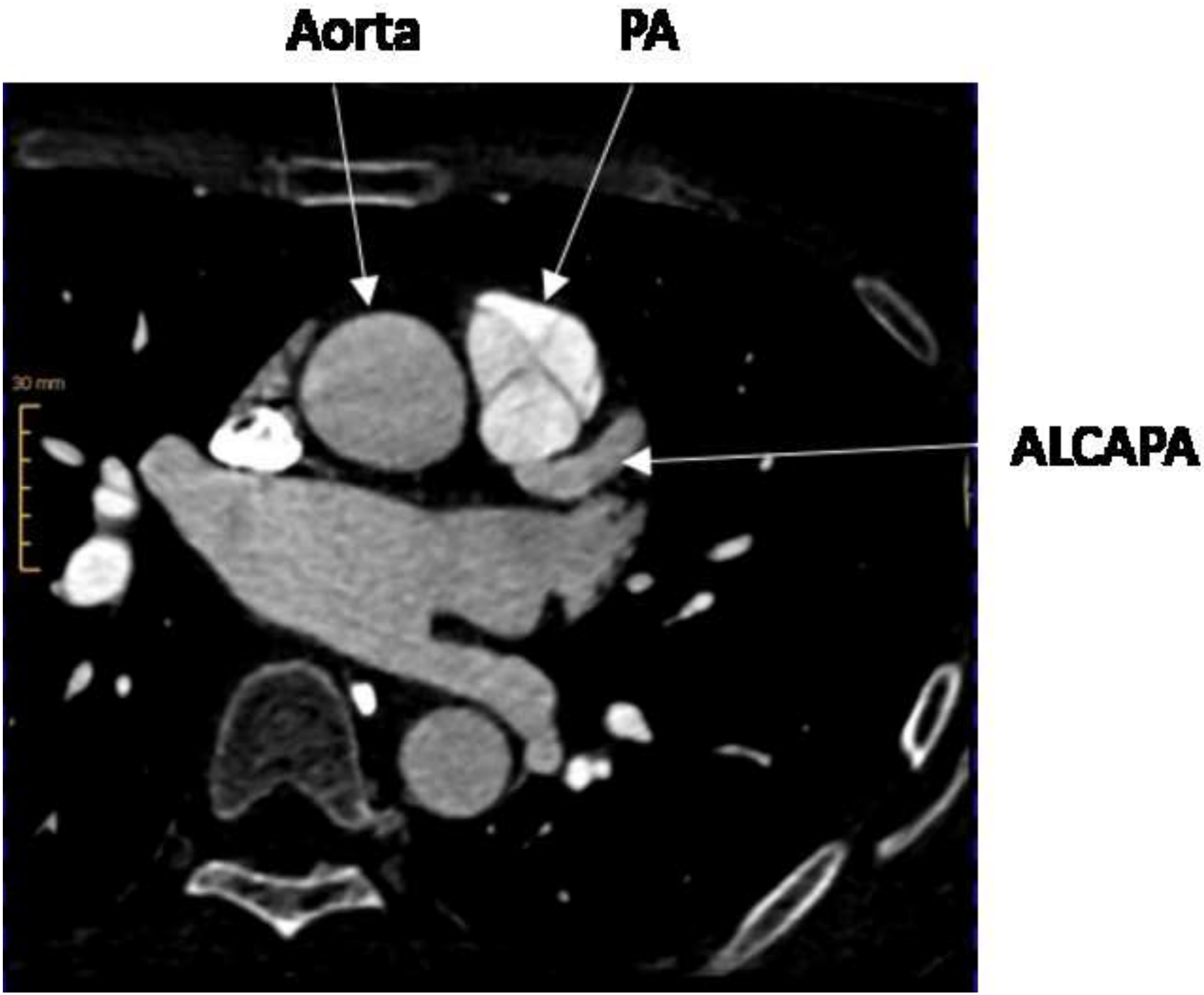

Figure 3

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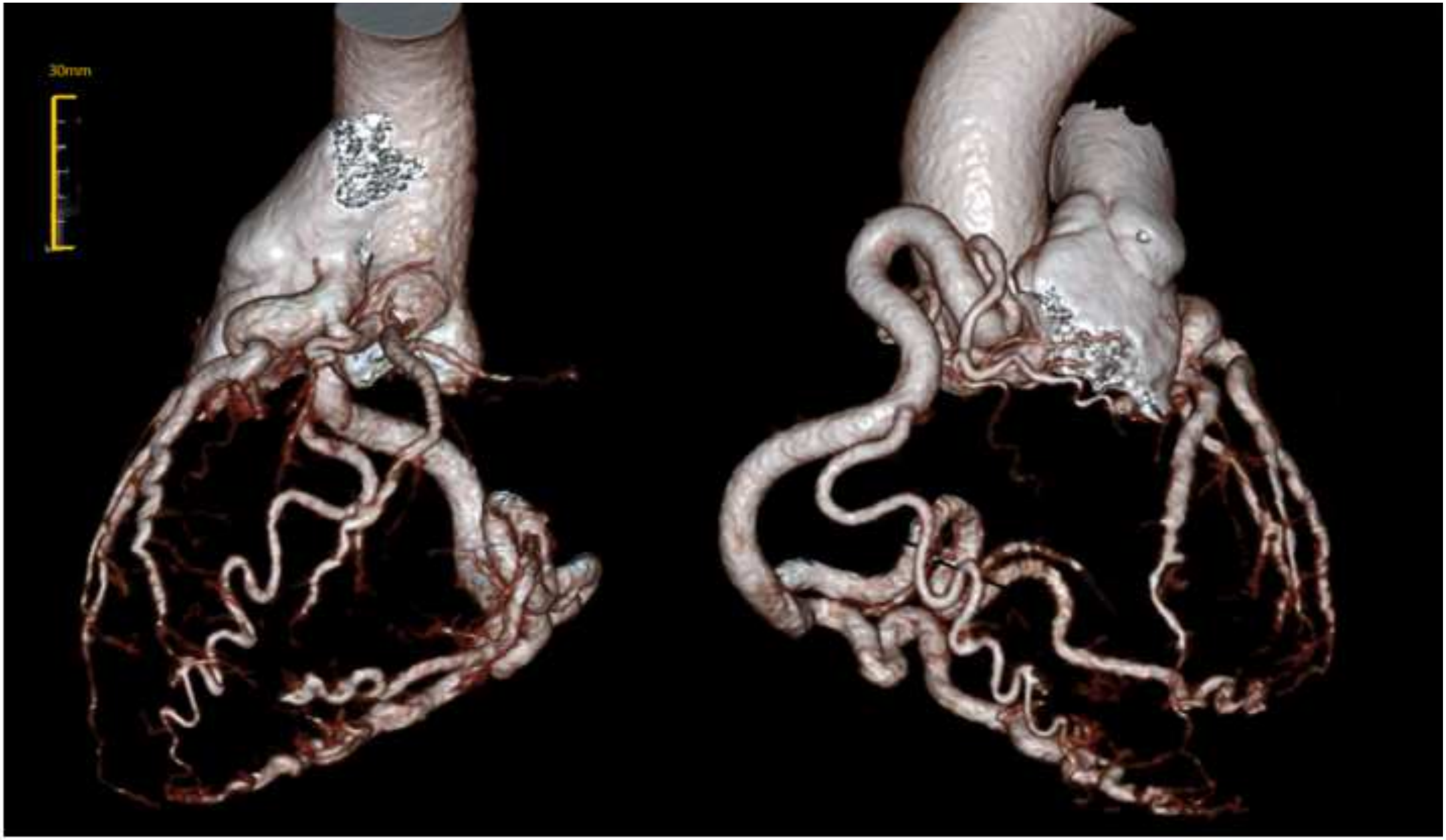

Left coronary artery from pulmonary artery

Right coronary artery from aorta

Figure 4

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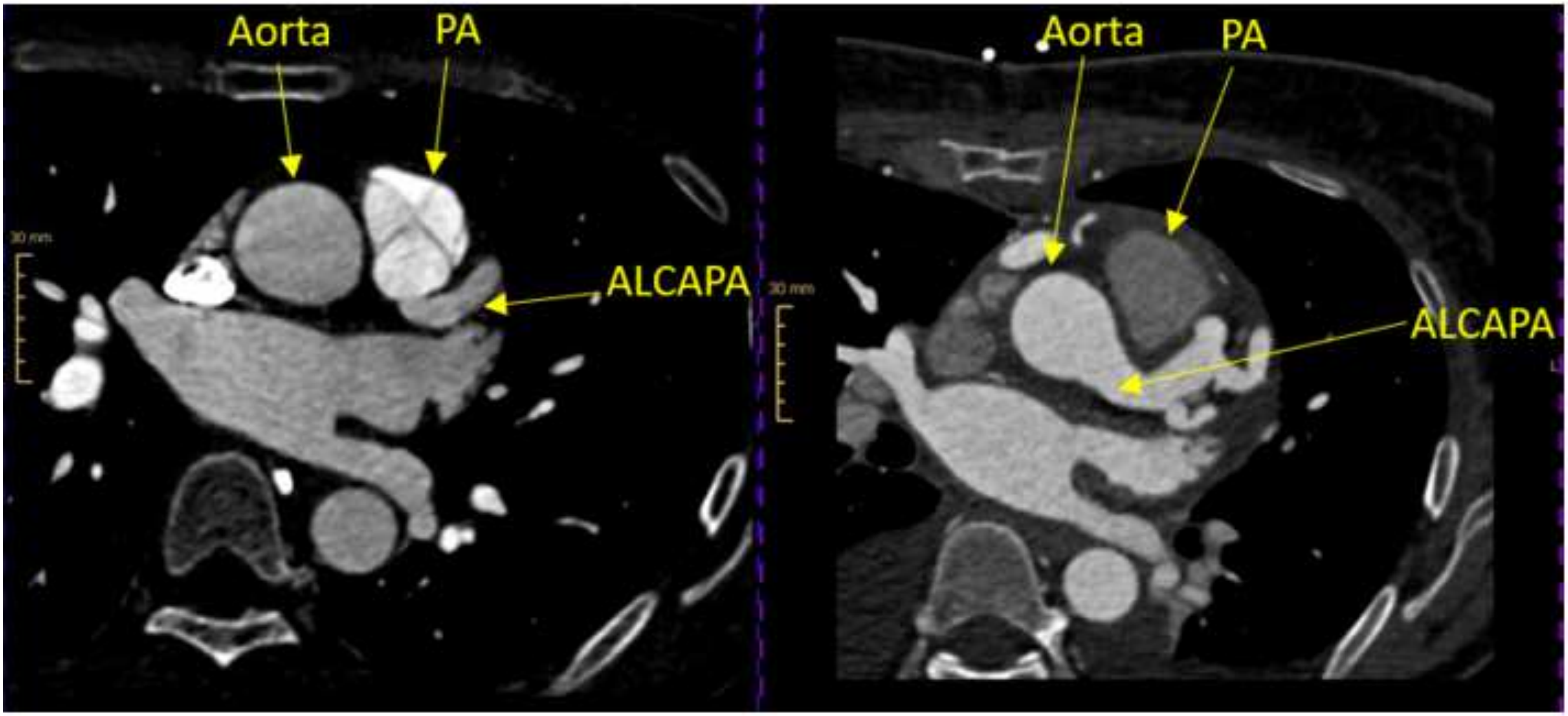

Pre-operative **Post-operative**

Name	Company
Heart surgery infrastructure:	
Heart Lung Machine	Stockert
EOPA 24Fr. arterial cannula	Medtronic
Quickdraw 25Fr. femoral venous cannula	Edwards
LV vent catheter 17Fr.	Edwards
Antegrade 9Fr. cardioplegia cannula	Edwards
Retrograde 14Fr. cardioplegia cannula	Edwards
Electrocautery	Covidien
Sutures:	
Polypropylene 4/0	Ethicon
Polypropylene 5/0	Ethicon
Polypropylene 6/0	Ethicon
Braided polyesther 2/0 ligature with polybutylate coating	Ethicon
Intergard dacron graft 8 mm	Maquet
Micro knife Sharpoint	TYCO Healthcare PTY
Drugs:	
Midazolam	Roche Pharma
Rocuronium	MSD Merck Sharp & Dohme
Propofol	Fresenius Kabi
Fentanil	Actavis
Instruments:	
Cooley Derra anastomosis clamp	Delacroix-Chevalier
Cooley vascular clamp	Delacroix-Chevalier
Dissection forceps Carpentier	Delacroix-Chevalier
Scissors Metzenbaum	Delacroix-Chevalier
Needle holder Ryder	Delacroix-Chevalier
Dissection forceps DeBakey	Delacroix-Chevalier
Micro needle holder Jacobson	Delacroix-Chevalier
Micro scisors Jacobson	Delacroix-Chevalier
Lung retractor	Delacroix-Chevalier
Allis clamp	Delacroix-Chevalier
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Leriche haemostatic clamp	Delacroix-Chevalier

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Author(s): Reza Tavakoli, Peiman Jamshidi, Nassrin Yamani, Max Gassmann

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Article Title: Technique of direct Reimplantation of left coronary artery into the aorta in anomalous left coronary artery from the pulmonary artery in adult

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Answers to editorial comments

• Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammatical errors.

The manuscript is proofread and the required modifications are written in red.

1) The title was edited for grammar and clarity.

I thank you for clarifying the title.

• Please include an ethics statement before your numbered protocol steps indicating that the protocol follows the guidelines of your institutions human research ethics committee.

This statement has been added.

• **Protocol Detail:**
1) 2.1.1: How is heparin administered here? Is it supplied through the IV line?

This information is added to the step.

2) 2.2.1: Please mention the starting point of the incision.

This information is added to the step.

3) 2.2.7: How is this secured?

This information is added to the step.

4) **Several of your filmed (highlighted) steps lack details. It is important that all actions are detailed to ensure good quality scripting and voice-over production. After matching the provided time stamps and steps, it appears that the video shows multiple actions that are not described. Please mention all surgical tools used (avoid commercial terms). Please mention any additional details as substeps (eg 2.1.1.X).**
Some examples are listed below:
a) 2.2.3: Please mention the surgical tool used for incision.

This information is added to the step. This step has been split into several action steps.

b) 2.2.4: How is the dissection done? Please mention this using a substep

This information is added to the step. This step has been split into several action steps.

c) 2.2.5: What type of loop is this? Is it tied?

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d) 2.2.8: How is the cannula secured? The video shows multiple actions that are not described involving steps to secure the cannulas.

This information is added to the step. This step has been split into several action steps.

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The numbering of the protocol section is readjusted to follow JoVE's instructions for authors with a one-line space between each protocol step.

• **Protocol Highlight:** Two video files were provided, please let us know which file matches the time stamps. The two files names are "Herz OP kurzere version" and "Herz OP Langversion".

The video file described is the "Herz OP kurzere version".

• **Discussion:**
1) Line 296: Do you mean pulmonary "artery"?

Yes, this has been added.

2) Lines 333-345: Please provide recommendations for estimating the elasticity, how do you choose patients? Are any imaging techniques such as ultrasound elastography or MR elastrography used?

Evaluation of appropriateness of tissue elasticity is clarified.

• **Figures:**: The scale references (1mm on figure= 2mm) were deleted as figures scale up and down on the final submission. The scale bars available on the figure are sufficient. Please ensure that they are correct.

The scale references are again added to the figures' legends.

• **Commercial Language:** Please replace Prolene with "polyethylene monofilament suture".

Prolene has been replaced by polypropylene.

• **Table of Materials:**Please revise the table of the essential supplies, reagents, and equipment. The table should include the name, company, and catalog number of all relevant materials/software in separate columns in an xls/xlsx file. Please include items such as dacron graft, clamps etc.

The Table of Materials has been expanded by adding the instruments, suture and electrocautery lacking in the previous version. The clamps and dacron graft were already referenced in the previous version.

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