Turkish Journal of Thoracic and Cardiovascular Surgery 2023;31(2):207-214

ORIGINAL ARTICLE / ÖZGÜN MAKALE

# Revisiting the central aortopulmonary shunt procedure

*Santral aortopulmoner şant ameliyatının yeniden gözden geçirilmesi*

**Baran Simsek[1], Arda Ozyuksel[1,2], Murat Saygi[3], Sener Demiroluk[4], Murat Basaran[1]**

*Institution where the research was done:*
Medicana International Hospital, Istanbul, Türkiye

*Author Affiliations:*
[1]Department of Cardiovascular Surgery, Medicana International Hospital, Istanbul, Türkiye
[2]Department of Cardiovascular Surgery, Biruni University, Istanbul, Türkiye
[3]Department of Pediatric Cardiology, Medicana International Hospital, Istanbul, Türkiye
[4]Department of Anesthesiology and Reanimation, Medicana International Hospital, Istanbul, Türkiye

## ABSTRACT

***Background:*** In this study, we present our experience with the central aortopulmonary shunt technique with interposing a polytetrafluoroethylene graft between main pulmonary artery (end-to-end) and the ascending aorta (side-to-side) in a variety of cyanotic congenital heart defects.

***Methods:*** Between January 2019 and June 2022, a total of 10 patients (6 males, 4 females; mean age: 4.3±2.8 months; range, 5 days to 10 months) with hypoplastic central pulmonary arteries who underwent central aortopulmonary shunt procedure were retrospectively analyzed. Demographic characteristics, preoperative, operative, and postoperative data of the patients were recorded. The Nakata indices of the patients were also noted before the procedure, as well as before the second stage of palliation or definitive repair.

***Results:*** Four (40%) patients were operated as the first-step palliation for univentricular circulation. Six (60%) patients had well-developed ventricles and were palliated to be treated with total correction. The median follow-up after the procedure was 12 (range, 8 to 16) months. The mean systemic arterial saturation level at room air was 89.3±2.9% during follow-up. No mortality was observed in any patient.

***Conclusion:*** A central aortopulmonary shunt procedure provides a reliable antegrade blood flow with a relatively non-challenging surgical technique that offers sufficient growth for the hypoplastic and confluent central pulmonary arteries with a very low risk of shunt thrombosis and overflow.

***Keywords:*** Cardiac, congenital heart disease, pulmonary artery, pulmonary vein, shunt.

## ÖZ

***Amaç:*** Bu çalışmada, çeşitli siyanotik doğumsal kalp hastalıklarında ana pulmoner arter (uç uca) ile çıkan aort (yan yana) arasında politetrafloroetilen greft interpozisyonu ile yapılan santral aortopulmoner şant tekniğine ilişkin deneyimimiz sunuldu.

***Çalışma planı:*** Ocak 2019 - Haziran 2022 tarihleri arasında santral aortopulmoner şant ameliyatı yapılan hipoplastik santral pulmoner arterlere sahip toplam 10 hasta (6 erkek, 4 kız; ort. yaş: 4.3±2.8 ay; dağılım, 5 gün-10 ay) retrospektif olarak incelendi. Hastaların demografik özellikleri, ameliyat öncesi, ameliyat sırası ve ameliyat sonrası verileri kaydedildi. Hastaların Nakata indeksleri de ameliyat öncesinde ve palyatif veya kesin onarımın ikinci aşamasından önce not edildi.

***Bulgular:*** Dört hasta (%40) tek ventrikül dolaşımı için birinci basamak palyasyon olarak ameliyat edildi. Altı hastada (%60) ventriküller iyi gelişmişti ve tam düzeltme ile tedavi edilmek üzere palyasyon yapıldı. Ameliyat sonrası medyan takip süresi 12 (dağılım, 8-16) ay idi. Takip sürecinde oda havasındaki ortalama sistemik arteriyel satürasyon düzeyi %89.3±2.9 idi. Hastaların hiçbirinde mortalite görülmedi.

***Sonuç:*** Santral aortopulmoner şant ameliyatı, şant trombozu ve aşırı yüklenme riski çok düşük olan, hipoplastik ve konfluent santral pulmoner arterler için yeterli büyüme sağlayabilen nispeten kolay bir cerrahi teknikle güvenli bir şekilde antegrad kan akımına imkan sağlar.

***Anahtar sözcükler:*** Kardiyak, doğumsal kalp hastalığı, pulmonary artery, pulmonary vein, shunt.

**Corresponding author:** Baran Simsek.
E-mail: simsekbaran@yahoo.com

Doi: 10.5606/tgkdc.dergisi.2023.24247

**Received:** September 30, 2022
**Accepted:** February 28, 2023
**Published online:** April 28, 2023

***Cite this article as:*** Simsek B, Ozyuksel A, Saygi M, Demiroluk S, Basaran M. Revisiting the central aortopulmonary shunt procedure.. Turk Gogus Kalp Dama 2023;31(2):207-214. doi: 10.5606/tgkdc.dergisi.2023.24247.

*©2023 All right reserved by the Turkish Society of Cardiovascular Surgery.*

*This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes (http://creativecommons.org/licenses/by-nc/4.0/).*

Hypoplastic pulmonary arteries (PAs) have been a significant challenge since the beginning of surgery for congenital heart defects and palliation has been deemed mandatory with a systemic-to-PA shunt procedure as a bridge to definitive treatment either with a univentricular or a biventricular physiology in patients with small, confluent and normally arborized intrapericardial branch PAs.[1] A central aortopulmonary shunt (CAPS) procedure is one of the techniques of systemic-to-PA shunts which aims to establish an initial palliation in a wide spectrum of cyanotic congenital heart diseases with hypoplastic PAs.[1] As with all other techniques of systemic-to-PA shunts, the main goal is to establish a sufficient blood flow to develop the hypoplastic pulmonary arterial bed, to improve hypoxia and cyanosis, as well as to provide somatic growth of the child.

The historical development of CAPS began 10 years after Blalock-Taussig (BT) shunt, in 1955, with the James Davidson's description of direct anastomosis of the main PA to the ascending aorta.[2] In 1962, CAPS with interposition of artificial graft materials was reported by Shumaker and Mandelbaum.[3] Later on, in 1987, Barragry et al.[4] reported promising results by implementing a polytetrafluoroethylene (PTFE) graft between the ascending aorta and main PA.[4] Consequently, the Melbourne group defined an updated technique by transecting the main PA from its proximal origin and reimplanting it directly to the lateral wall of the aorta with an end-to-side anastomosis.[5] Melbourne shunt was also described and termed by Mumtaz et al.[6] with a focus on the significant growth potential of the diminutive PA. Another creative technique termed as a 'Laks-type' side-to-side anastomosis of a PTFE shunt to the ascending aorta was reported by Gates et al.[7] in 1998. Barozzi et al.[8] reported their encouraging results in terms of PA growth potential with their modified Laks technique.

In this study, we aimed to present our experience with the CAPS technique with interposing a PTFE graft between main PA (end-to-end) and the ascending aorta (side-to-side) in a variety of cyanotic congenital heart defects to seek the most optimal shunt technique to provide maximal growth of the pulmonary vasculature.

## PATIENTS AND METHODS

This single-center, retrospective study was conducted at Medicana International Hospital, Department of Pediatric Congenital Cardiac Surgery between January 2019 and June 2022. A total of 10 patients (6 males, 4 females; mean age: 4.3±2.8 months; range, 5 days to 10 months) with hypoplastic central PAs who underwent CAPS surgery were included. Patients were enrolled in an indefinite follow-up scheme and data were subsequently entered prospectively in a computerized database. Patients' demographic characteristics, preoperative, operative, and postoperative data were recorded. The Nakata indices of the patients were noted before the CAPS procedure, as well as before the second stage of palliation or definitive repair.

The patients with pulmonary atresia and additional cardiac malformations including ventricular septal defect (VSD), VSD and major aortopulmonary collateral arteries (MAPCAs), tricuspid atresia (TA), congenitally corrected transposition of the great arteries (ccTGA), and mitral valve hypoplasia (MVH) underwent a modified CAPS procedure with an end-to-end anastomosis of the shunt to the main PA.

### Surgical technique

A standard median sternotomy was performed in all patients. After subtotal excision of the thymus, pericardium was opened wide enough to provide exposure of the aorta and the PAs. The ascending aorta, main PA and left and right branches were mobilized. A testing vascular clamp was applied to the main PA to make a decision whether the patient was able to tolerate the surgical process without utilizing cardiopulmonary bypass (CPB). If the surgery was amenable to be performed without CPB, 100 U/kg intravenous heparin was administered and after confirming an activated clotting time (ACT) over 200 sec, and the main PA was transected at its origin at the right ventricular outflow. The proximal stump of the PA was oversewn with double-row 6/0 polypropylene sutures and secured with two surgical clips. The expanded PTFE (ePTFE) graft was anastomosed in an end-to-end fashion to the main PA with 7/0 polypropylene suture. The side-to-side proximal anastomosis of the graft was performed after positioning a Castaneda clamp to the lateral site of the ascending aorta. The ostium at the aorta was opened with a punch bite, whereas a scalpel No. 11 was used to vertically incise the graft. The most proximal part of the graft stump was folded and closed with double row 6/0 polypropylene sutures and secured with one or two surgical clips (Figure 1).

All of the CAPS procedures were completed without CPB support, except for Patients No. 9 and 10, where an atrial septectomy was deemed mandatory to augment interatrial mixing. In these patients, CAPS were performed under CPB and, at the time of atrial septectomy, a single-dose blood cardioplegia was administered. After completion of both proximal and

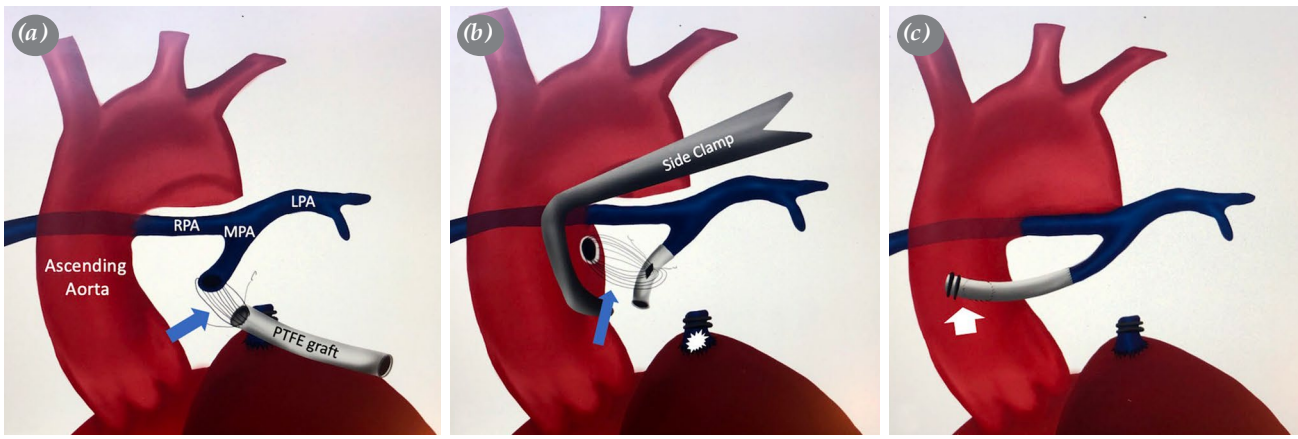


**Figure 1.** Operative technique. **(a)** The main pulmonary artery is transected at its origin distal to the right ventricle and a PTFE graft is anastomosed with an end-to-end fashion (arrow). **(b)** Afterwards, a side clamp is placed at the ascending aorta and the proximal end of the graft is anastomosed in a side-to-side fashion (arrow), leaving a stump of main pulmonary artery at its origin (asterisk). **(c)** The proximal stump of the graft proximal to the side-to-side anastomosis is sutured and clipped (arrow).
RPA: Right pulmonary artery; LPA: Left pulmonary artery; MPA: Main pulmonary artery; PTFE: Polytetrafluoroethylene.

distal anastomosis of the shunts and removal of the vascular clamps, a 5 to 10 mmHg drop in diastolic arterial pressure and 85 to 90% systemic arterial oxygen saturation ($SaO_2$) level were targeted under fraction of inspired oxygen ($FiO_2$) of 50%. Heparin infusion was initiated after hemostasis while the sternum was still open, based on the ACT values before the patients were transferred to the intensive care unit (ICU). During the first 72 h postoperatively, 1 mg/kg/h of intravenous heparin infusion was administered and the dose was adjusted according to the ACT levels. Afterwards, the total daily heparin dose was administered in three to four divided injections per day. Oral acetylsalicylic acid was administered at 5 mg/kg/day beginning from the first postoperative day.

### Statistical analysis

Statistical analysis was performed using the IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency.

## RESULTS

The demographic, preoperative, and postoperative characteristics of the patients are summarized in Table 1. Four (40%) patients were operated as the first-stage palliation for univentricular physiology, while six (60%) patients had well-developed ventricles and were palliated to be treated with total correction. The common feature of all patients was confluent, but hypoplastic PAs. We routinely performed preoperative cardiac catheterization, as well as contrast-enhanced computed tomographic angiography (CTA), except for Patient No. 10 who was operated on the fifth day after birth. Patients No. 3, 5, 9 and 10 were candidates for univentricular repair.

All of the grafts were placed via a median sternotomy. We used 3-mm ePTFE grafts in Patient No. 4; 3.5-mm ePTFE grafts in Patients No. 3, 5 and 10, and 4-mm ePTFE grafts in Patients No. 1, 2, 6, 7, 8 and 9.

None of the patients were extubated in the early postoperative period, particularly to evaluate the function of the shunt, as well as overflow. We routinely performed two or three chest X-rays during the first postoperative 24 h seeking for any oligemia or overflow at the lung parenchyma. All of the patients were evaluated with transthoracic echocardiography (TTE) at the first hours after admission to the ICU. All of the grafts were patent, except for Patient No. 8 who had early graft thrombosis, although the ACT was kept around 180 sec. This patient was reoperated and the thrombus was removed through the proximal stump of the shunt. No early or late graft failure/thrombosis was observed.

Patient No. 9 had radiological findings of excessive blood flow to the pulmonary vascular bed at the early postoperative hours (Figure 2). In such cases, we routinely provide intravenous fluid restriction to 1 to 3 mL/kg/h, aggressive diuresis, and dopamine

**Table 1. Demographic, preoperative, and postoperative characteristics of the patients**

| Patient no. | Age/BW (g) | Diagnosis | Nakata Index-1† ($mm/m^2$) | Nakata Index-2‡ ($mm/m^2$) | Preoperative $SaO_2$ (%)Φ | Postoperative $SaO_2$ (%)Φ | Follow-up | Graft size (mm) | Inter-stage Period between CAPS and second intervention |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 months/5,700 | VSD, PA, MAPCAs | 66.9 | StagingΦΦΦ | 70 | 92 | StagingΦΦΦ | 4 | Staging |
| 2 | 3 months/5,100 | VSD, PA, PDA | 78.4 | StagingΦΦΦ | 55 | 89 | StagingΦΦΦ | 4 | Staging |
| 3 | 4 months /3,600 | TA, VSD, PA, ASD, PDA | 157.3 | 296.8 | 65 | 88 | BDG | 3.5 | 8 months |
| 4 | 12 days /2,300 | VSD, PA, PDA | 101.8 | 298.3 | 60 | 92 | Correction | 3 | 10 months |
| 5 | 4 months/5,400 | TA, VSD, PA, PDA | 144.8 | 307.8 | 55 | 84 | BDG | 3.5 | 10 months |
| 6 | 6 months/6,400 | VSD, PA, MAPCAs | 119.8 | 324.3 | 72 | 92 | Correction | 4 | 10 months |
| 7 | 6 months/6,000 | VSD, PA, ASD, MAPCAs | 72.8 | 188.7 | 60 | 85 | Correction | 4 | 12 months |
| 8 | 6 months/5,000 | VSD, PA, ASD, PDA, MAPCAs | 67.6 | 197.3 | 55 | 89 | Correction | 4 | 16 months |
| 9 | 10 months/6,300 | ccTGA, MVH, LVH, PA | 78.5 | 180.2 | 60 | 91 | BDG | 4 | 8 months |
| 10 | 5 days/3,600 | IVS, PA, RVH, ASD, PDA | 85.2 | 186.7 | 58 | 90 | BDG | 3.5 | 12 months |

BW: Body weight; CAPS: Central aortopulmonary shunt; VSD: Ventricular septal defect; PA: Pulmonary atresia; MAPCAs: Major aortopulmonary collaterally arteries; PDA: Patent ductus arteriosus; TA: Tricuspid atresia; ASD: Atrial septal defect; cc-TGA: Congenitally corrected transposition of great arteries; MVH: Mitral valve hypoplasia; LVH: Left ventricular hypoplasia; IVS: Intact ventricular septum; RVH: Right ventricular hypoplasia; BDG: Bidirectional Glenn procedure; † Pulmonary artery index before CAPS procedure; ‡ Pulmonary artery index before BDG or total correction procedure; Φ Systemic arterial oxygen saturation level before CAPS procedure; ΦΦ Systemic arterial oxygen saturation after CAPS procedure; ΦΦΦ Patients listed for future total correction procedure.

infusion at renal dose. We intervene systemic blood pressure to keep peak values below 90 to 100 mmHg. Patient No. 9 overcame overflow uneventfully and was extubated on postoperative Day 2 after the operation. The median extubation time in the ICU was 12 (range, 6 to 36) h. The median length of ICU stay and hospital stay was 3 (range, 2 to 5) days and 10 (range, 7 to 14) days, respectively. The median duration of drainage was 3 (range, 2 to 4) days.

Second operations included bidirectional Glenn (BDG) procedure for Patients No. 3, 5, 9 and 10, whereas the rest of the patients underwent definitive biventricular repair. None of the patients with a BDG procedure underwent Fontan completion during follow-up. Patients No. 1 and 2 are still in staging period for a preliminary biventricular repair. Before the second surgical interventions, all of the patients underwent either a diagnostic cardiac catheterization or CTA to assess the development of the PAs in terms of PA (Nakata) indices (Figure 3). The mean Nakata indices and systemic $SaO_2$ values of the Patients No. 3, 4, 5, 6, 7, 8, 9 and 10 before the time of second operations were 247.5±64.1 $mm/m^2$ and 89.3±2.9%, respectively. The mean Nakata indices increased from 113.6±44.1 $mm/m^2$ to 209.1±87.8 $mm/m^2$ in a median time period of nine months, except for Patients No. 1 and 2 whom are still waiting in stating period and the final indices have not been evaluated yet.

After a median follow-up of 10.5 (range, 8 to 12) months, Stage 2 BDG was completed in Patients No. 3, 5, 9, and 10 who are candidates for Stage 3 Fontan palliation in the future. Patients No. 4, 6, 7, and 8 underwent total correction after a median follow-up of 14 (range, 10 to 16) months. Patients No. 1 and 2 are still under follow-up for a future total correction procedure. Patients No. 1, 6, 7, and 8 had both two MAPCAs. The areas that were supplied by the MAPCAs were also dually supplied by the normally arborized and confluent PAs. No postoperative necessity for MAPCA closure was observed. Coil closure of MAPCAs in Patients No. 6, 7, and 8 were successfully performed immediately before total correction procedures.

The median follow-up after modified CAPS procedure was 12 (range, 8 to 16) months. The mean systemic arterial saturation level at room air was 89.3±2.9% (range, 84 to 92%) during follow-up. No mortality was encountered in any patient.

## DISCUSSION

Cyanotic patients who have a hypoplastic pulmonary vascular bed or diminutive PAs have been a challenge for cardiovascular surgeons, as well as pediatric

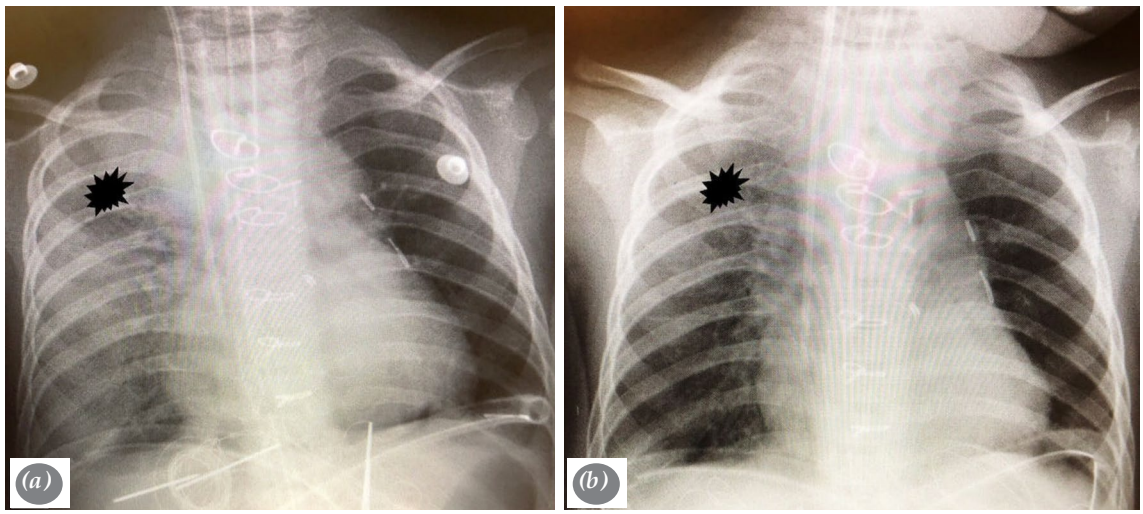


**Figure 2.** Chest X-ray of an overflow following central aortopulmonary shunt procedure. **(a)** The parenchyma of the right lung demonstrates the findings of congestion (asterisk). **(b)** The findings disappear at the same field following medical management (asterisk).

cardiologists for a long period of time. Beginning from the early efforts by Taussig and Blalock followed by Davidson,[2] the congenital heart teams sought for a systemic-to-PA shunt method which should be reliable in terms of adequate blood flow.

A CAPS gained a significant credibility as a reliable alternative to provide the first step palliation in a variety of cyanotic congenital heart defects with hypoplastic/diminutive central PAs. End-to-end fashioned anastomosis of the tubular graft to the main pulmonary artery (MPA) was speculated to provide a more physiological blood flow to branch PA probably related to more anatomical position of the angle between the graft and MPA.[4-8] On the other hand, midline sternotomy has become the preferred choice of surgical approach in the last decades in patients undergoing an aortopulmonary shunt procedure, which provides an optimal view of both the aorta and the PAs with taking the advantage of utilizing CPB, when necessary.[9,10]

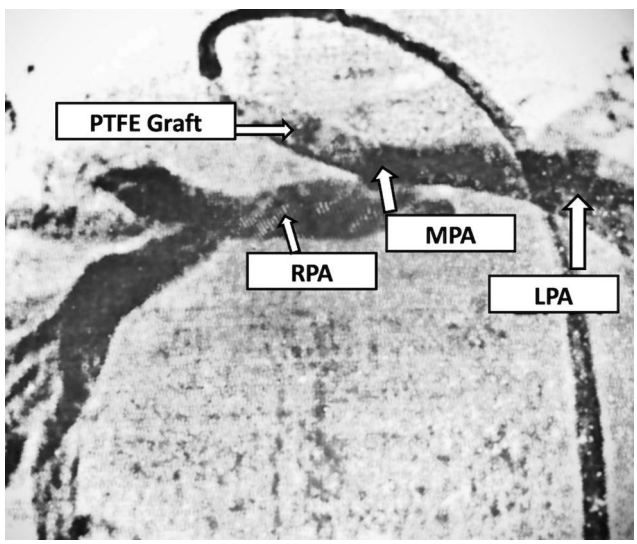


**Figure 3.** An angiography demonstrating the patent PTFE graft that provides unobstructed blood flow to the branch pulmonary arteries after central aortopulmonary shunt procedure.

PTFE: Polytetrafluoroethylene; RPA: Right pulmonary artery; MPA: main pulmonary artery; LPA: Left pulmonary artery.

One of the main parameters for the faith of a cyanotic patient undergoing a shunt procedure is to provide a symmetric and adequate growth in both central and branch PAs. The CAPS procedure can provide such satisfactory development of the pulmonary vascular bed either in univentricular or biventricular hearts.[11-13] The PA (Nakata) index is an important determinant in these patients and, in our patient population, the mean Nakata indices increased from 113.6±44.1 mm/m$^2$ to 209.1±87.8 mm/m$^2$ in a median time period of nine months, except for Patients No. 1 and 2 who are still in the staging period and the final indices have not been evaluated yet.

In any type of central systemic-to-PA shunt procedure, the site of the anastomosis on the aorta gains importance, which is a significant parameter for graft configuration in terms of avoiding kinking,

thrombosis and distortion.[14] We usually prefer to anastomose the proximal end of the PTFE graft to the lateral wall of the aorta, slightly to the posterior. This location allows us to interpose a shorter graft. Moreover, since the graft becomes far away from sternum, re-sternotomy and aortic cannulation may be performed relatively safely in the following stages, compared to the patients having a shunt just beneath the sternum. The side-to-side anastomosis of the graft to the aorta provides an excellent access to the graft in case of early graft thrombosis. Following the removal of the surgical clips and opening the stump allows to remove the clot, flush the graft and the branch PAs with heparin containing saline. The anastomotic sutures at the proximal and distal end are left untouched. This maneuver may be repeated, when necessary, in case a reintervention is deemed mandatory. On the other hand, this site of proximal graft anastomosis is speculated to be an easier location for a safe and easy route for catheter-based diagnosis or intervention, when necessary.[15] In our practice, we mobilize both the left and right branches of the PA to the hilus of the lungs bilaterally. This may avoid PA distortion by reducing the traction on the graft.

The shunt size plays an important role in these patients, since there are two ends of the sword both at the smaller and large size grafts. A smaller graft carries the risk of early thrombosis, as well as being inadequate for providing adequate blood flow for the development of the pulmonary vascular bed. A larger shunt may lead to overflow and congestive heart failure. The 3-mm shunt is reported to have a higher incidence for early graft thrombosis.[16,17] We performed CAPS with a 3-mm graft only in one patient, with a 3.5-mm shunt in three patients, and 4-mm in six patients. Despite effective intravenous heparinization with a reasonable ACT level between 170 and 180 was achieved, we encountered early thrombosis of a 4-mm PTFE graft in one patient (Patient No. 8) at the first postoperative hour. We removed the thrombosis from the graft at the operation theater and the patient uneventfully recovered and discharged.

Occluding or dividing a patent ductus arteriosus routinely at the time of shunt operation is debated in patients undergoing systemic-to-PA shunts; however, experiences have documented segmental narrowing of the proximal main or left PA at the site of ductal opening due to traction.[18] In our experience, Patients No. 2, 3, 4, 5, 8, and 10 had concomitant PDAs, which we ligated and divided. In such cases, the dual pulmonary blood flow (PBF) source may possess the risk of overflow, coronary steal and subsequent myocardial dysfunction with regard to the untoward effects of decreased coronary perfusion pressure.

In the current era, shunt procedures are still widely used in patients with ductal-dependent PBF. The PDA stent placement has emerged as an alternative to surgical shunt palliation. In 1992, stenting PDA was described as an alternative to shunt procedures to provide PBF, and the use of this technique has expanded considerably since then.[19-21] The PDA stenting has the advantages of being less invasive, thereby avoiding a median sternotomy or lateral thoracotomy, potentially avoiding exposure to CPB, and potentially allowing for more symmetric growth of the PAs.[22] On the other hand, potential disadvantages of PDA stenting include procedural complications unique to this procedure, particularly vascular access-related, concerns regarding stent longevity, and potential problems related to the ductal stent during subsequent surgical procedures.[23] The most optimal strategy while PDA stenting and performing a surgical systemic-to-PA shunt is still debated in the literature in which no definite consensus is available.

The mortality rate of modified BT shunt varies in the literature; patients with a univentricular physiology and a biventricular physiology have mortality rates of 15% and 3 to 5%, respectively.[24,25] The traditional techniques of systemic-to-PA shunt creation such as Potts, Waterston, and Cooley are not routinely used in the modern era of congenital cardiac surgery, probably with regard to the uncontrolled PBF and challenges at the reoperation for taking down.[26]

Congestive heart failure due to excessive additional pulmonary blood related to MAPCAs is another issue debated in the literature, whereas the body weight, underlying cardiac pathology, development of the distal pulmonary vascular bed are all determinants of shunt size selection and occluding MAPCAs.[27,28] In cases with a stenotic MAPCA, a larger shunt size may be chosen. In the current study, we encountered one case (Patient No. 9) with a MAPCA that the clinical and radiological findings of pulmonary overflow was detected and the patient was medically treated and uneventfully discharged.

Strategy in patients who require a shunt with the PAs are not hypoplastic such as a single-ventricle patient with pulmonary atresia and ductus-dependent pulmonary circulation is another debate. In general, we do not prefer CAPS technique in patients in whom the PA development is satisfactory. When the patients with univentricular physiology are considered, there are two clinical scenarios. In the first and more common clinical set-up, patients who require systemic-to-PA

shunts as an initial palliative stage without diminutive PAs, we prefer to perform subclavian to branch PA graft interposition with median sternotomy. In our clinical experience, this practice provides us two important advantages. First, utilization of side branch for relieving systemic desaturation helps us to maintain the pulmonary vascular geometry in an undistorted fashion as much as possible. In this case, we select the proximal parts of the branch PAs for the distal anastomosis of the graft rather than going more distal to the hilar region. Undoubtedly, median sternotomy provides excellent exposure compared to thoracotomy. In the second clinical scenario, as we encountered in our Patients No. 3, 5, 9, and 10, patients with hypoplastic vascular bed who would eventually end up with univentricular palliation but having diminutive pulmonary arteries, the CAPS procedure may have important advantages. First of all, symmetrical growth potential of the branch PAs bilaterally can be obtained with the CAPS procedure. Secondly, take-down of the CAPS is not technically challenging in Stage 2 palliation. Moreover, the site at which cavopulmonary anastomosis would be performed would be far away from the site of the CAPS graft insertion; i.e., the pulmonary bifurcation. In our case series, we performed CAPS procedure for univentricular Stage 1 palliation in Patients No: 3, 5, 9, and 10; all the patients had Nakata indices below 157 mm/m$^2$. We proceeded to Stage 2 palliation with take-down of the CAPS procedure in all of these patients with satisfactory PA growth. On the other hand, we encountered one patient with pulmonary overflow which was treated medically. Pulmonary vascular bed palliated with central shunts are always prone to overflow, when well-developed PAs are considered. As a result, probably patient selection is the major criterion to choose the technique of systemic-to-PA shunt at different underlying pathological conditions. We usually do not prefer the CAPS technique in patients with well-developed PAs to reduce the risk of pulmonary overflow.

Although we mostly achieved our prespecified treatment targets, our patient population is not enough to make a firm conclusion. The single-center, retrospective design of the study with a relatively small sample size is the main limitation.

In conclusion, a central aortopulmonary shunt procedure is an excellent way of providing adequate blood flow from systemic arteries to the pulmonary vascular bed. The technique is less demanding and the proximal side-to-side anastomosis enhances possible secondary surgical interventions which may be deemed mandatory in the postoperative period. On the other hand, take-down of the shunt at the re-sternotomy is relatively safer. In our limited experience, the growth of the hypoplastic and confluent central pulmonary arteries is satisfactory with a low risk of shunt thrombosis and overflow.

**Ethics Committee Approval:** The study protocol was approved by the Medicana International Istanbul Hospital Ethics Committee (date: 11.01.2022, no: 041). The study was conducted in accordance with the principles of the Declaration of Helsinki.

**Patient Consent for Publication:** A written informed consent was obtained from the parents and/or legal guardians of the patients.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Author Contributions:** Conceptualization: B.S., A.O.; Formal analysis: B.S.; Data curation: B.S., M.S.; Writing-original draft: B.S., S.D.; Critical revision of the article, writing-review and editing: B.S., A.O., M.B.

**Conflict of Interest:** The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

**Funding:** The authors received no financial support for the research and/or authorship of this article.

## REFERENCES

1. Fang M, Wang H, Jin Y, Wang Z, Wang Z, Zhang C. Development of pulmonary arteries after a central end-to-side shunt in patients with pulmonary atresia, ventricular septal defect, and diminutive pulmonary arteries. Thorac Cardiovasc Surg 2014;62:211-5. doi: 10.1055/s-0033-1354247.
2. Davidson JS. Anastomosis between the ascending aorta and the main pulmonary artery in the tetralogy of Fallot. Thorax 1955;10:348-50. doi: 10.1136/thx.10.4.348.
3. Sumacker HB Jr, Mandelbaum I. Ascending aorticpulmonary artery shunts in cyanotic heart disease. Surgery 1962;52:675-8.
4. Barragry TP, Ring WS, Blatchford JW, Foker JE. Central aorta-pulmonary artery shunts in neonates with complex cyanotic congenital heart disease. J Thorac Cardiovasc Surg 1987;93:767-74.
5. Watterson KG, Wilkinson JL, Karl TR, Mee RB. Very small pulmonary arteries: Central end-to-side shunt. Ann Thorac Surg 1991;52:1132-7. doi: 10.1016/0003-4975(91)91294-6.
6. Mumtaz MA, Rosenthal G, Qureshi A, Prieto L, Preminger T, Lorber R, et al. Melbourne shunt promotes growth of diminutive central pulmonary arteries in patients with pulmonary atresia, ventricular septal defect, and systemic-to-pulmonary collateral arteries. Ann Thorac Surg 2008;85:2079-83. doi: 10.1016/j.athoracsur.2008.01.098.
7. Gates RN, Laks H, Johnson K. Side-to-side aorto-Gore-Tex central shunt. Ann Thorac Surg 1998;65:515-6. doi: 10.1016/s0003-4975(97)01126-0.

8. Barozzi L, Brizard CP, Galati JC, Konstantinov IE, Bohuta L, d'Udekem Y. Side-to-side aorto-GoreTex central shunt warrants central shunt patency and pulmonary arteries growth. Ann Thorac Surg 2011;92:1476-82. doi: 10.1016/j.athoracsur.2011.05.105.
9. Brooks A. Systemic-pulmonary artery shunts in infants: Modified Blalock-Taussig and central shunt procedures. Multimed Man Cardiothorac Surg 2014;2014:mmu007. doi: 10.1093/mmcts/mmu007.
10. Myers JW, Ghanayem NS, Cao Y, Simpson P, Trapp K, Mitchell ME, et al. Outcomes of systemic to pulmonary artery shunts in patients weighing less than 3 kg: Analysis of shunt type, size, and surgical approach. J Thorac Cardiovasc Surg. 2014 Feb;147(2):672-7. doi: 10.1016/j.jtcvs.2013.09.055.
11. Bao M, Li H, Pan G, Xu Z, Wu Q. Central shunt procedures for complex congenital heart diseases. J Card Surg 2014;29:537-41. doi: 10.1111/jocs.12343.
12. Rodefeld MD, Reddy VM, Thompson LD, Suleman S, Moore PC, Teitel DF, et al. Surgical creation of aortopulmonary window in selected patients with pulmonary atresia with poorly developed aortopulmonary collaterals and hypoplastic pulmonary arteries. J Thorac Cardiovasc Surg 2002;123:1147-54. doi: 10.1067/mtc.2002.121685.
13. Piskin S, Altin HF, Yildiz O, Bakir I, Pekkan K. Hemodynamics of patient-specific aorta-pulmonary shunt configurations. J Biomech 2017;50:166-71. doi: 10.1016/j.jbiomech.2016.11.014. Epub 2016 Nov 11.
14. Tireli E, Ugurlucan M, Banach M. eComment: The anastomosis between aorta and extension conduit of the pulmonary artery. Interact Cardiovasc Thorac Surg 2008;7:194. doi: 10.1510/icvts.2007.170720A.
15. Cools B, Brown SC, Boshoff DE, Eyskens B, Heying R, Rega F, et al. Percutaneous intervention for central shunts: New routes, new strategies. Acta Cardiol 2017;72:142-8. doi: 10.1080/00015385.2017.1291156.
16. O'Connor MJ, Ravishankar C, Ballweg JA, Gillespie MJ, Gaynor JW, Tabbutt S, et al. Early systemic-to-pulmonary artery shunt intervention in neonates with congenital heart disease. J Thorac Cardiovasc Surg 2011;142:106-12. doi: 10.1016/j.jtcvs.2010.10.033.
17. Santro T, d'Udekem Y, Zannino D, Hobbes B, Konstantinov IE, Brizard C, et al. Determinants of acute events leading to mortality after shunt procedure in univentricular palliation. J Thorac Cardiovasc Surg 2019;158:1144-53.e6. doi: 10.1016/j.jtcvs.2019.03.126.
18. Waldman JD, Karp RB, Gittenberger-de Groot AC, Agarwala B, Glagov S. Spontaneous acquisition of discontinuous pulmonary arteries. Ann Thorac Surg 1996;62:161-8. doi: 10.1016/0003-4975(96)00229-9.
19. Gibbs JL, Rothman MT, Rees MR, Parsons JM, Blackburn ME, Ruiz CE. Stenting of the arterial duct: A new approach to palliation for pulmonary atresia. Br Heart J 1992;67:240-5. doi: 10.1136/hrt.67.3.240.
20. Santoro G, Gaio G, Giugno L, Capogrosso C, Palladino MT, Iacono C, et al. Ten-years, single-center experience with arterial duct stenting in duct-dependent pulmonary circulation: Early results, learning-curve changes, and mid-term outcome. Catheter Cardiovasc Interv 2015;86:249-57. doi: 10.1002/ccd.25949.
21. Udink Ten Cate FE, Sreeram N, Hamza H, Agha H, Rosenthal E, Qureshi SA. Stenting the arterial duct in neonates and infants with congenital heart disease and duct-dependent pulmonary blood flow: A multicenter experience of an evolving therapy over 18 years. Catheter Cardiovasc Interv 2013;82:E233-43. doi: 10.1002/ccd.24878.
22. Santoro G, Gaio G, Capozzi G, Giugno L, Palladino MT, Capogrosso C, et al. Fate of hypoplastic pulmonary arteries after arterial duct stenting in congenital heart disease with duct-dependent pulmonary circulation. JACC Cardiovasc Interv 2015;8:1626-32. doi: 10.1016/j.jcin.2015.05.027.
23. Sivakumar K, Bhagyavathy A, Coelho R, Satish R, Krishnan P. Longevity of neonatal ductal stenting for congenital heart diseases with duct-dependent pulmonary circulation. Congenit Heart Dis 2012;7:526-33. doi: 10.1111/j.1747-0803.2012.00657.x.
24. Petrucci O, O'Brien SM, Jacobs ML, Jacobs JP, Manning PB, Eghtesady P. Risk factors for mortality and morbidity after the neonatal Blalock-Taussig shunt procedure. Ann Thorac Surg 2011;92:642-51. doi: 10.1016/j.athoracsur.2011.02.030.
25. McKenzie ED, Khan MS, Samayoa AX, Vener DS, Ishak YM, Santos AB, et al. The Blalock-Taussig shunt revisited: A contemporary experience. J Am Coll Surg 2013;216:699-704. doi: 10.1016/j.jamcollsurg.2012.12.027.
26. Truccone NJ, Bowman FO Jr, Malm JR, Gersony WM. Systemic-pulmonary arterial shunts in the first year of life. Circulation 1974;49:508-11. doi: 10.1161/01.cir.49.3.508.
27. Dirks V, Prêtre R, Knirsch W, Valsangiacomo Buechel ER, Seifert B, Schweiger M, et al. Modified Blalock Taussig shunt: A not-so-simple palliative procedure. Eur J Cardiothorac Surg 2013;44:1096-102. doi: 10.1093/ejcts/ezt172.
28. Bove T, Vandekerckhove K, Panzer J, De Groote K, De Wolf D, François K. Disease-specific outcome analysis of palliation with the modified Blalock-Taussig shunt. World J Pediatr Congenit Heart Surg 2015;6:67-74. doi: 10.1177/2150135114558690.