Stent or Shunt, what could be better for children with duct dependent pulmonary circulation?
Stent or Shunt, What Could be Better for Children with Duct Dependent Pulmonary Circulation?

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Abstract

\textit{Background:} Systemic to pulmonary shunt (Shunt) is offered for children with duct dependent pulmonary circulation to augment pulmonary flow. Recently patent ductus arteriosus (PDA) stent (Stent) is widely used as an alternative method. We aimed to compare post intervention outcomes in children underwent either procedure.

\textit{Methods:} Infants under 3 months who had an initial palliation by Shunt or Stent were retrospectively reviewed between 2008 and 2016, then followed till the second intervention or 1 year whichever earlier.

\textit{Results:} 187 patients (110 Shunt and 77 Stent) were included. Initial weight and pulmonary artery (PA) branches size were similar between the groups. Shunt patients had more shock preoperatively and required more emergency intervention. Stent group showed less ICU stay 4 (1–8) vs 13 (7–23) days, \( p < 0.0001 \) and less positive pressure ventilation days 1 (0–2) vs 5.5 (3–11), \( p < 0.0001 \). However, Stent group had more symptomatic arterial and deep venous thromboses. In Stent patients the branch PAs growth was better and more homogeneous. At follow-up, no difference between groups regarding cumulative readmission days to hospital, hemoglobin levels and the weight percentile for age. Mortality was not different with a tendency to be higher in the Shunt group (13\%) compared to the Stent group (5\%), \( p \ 0.1 \).

\textit{Conclusions:} The implantation of PDA stent in patients with duct dependent pulmonary circulation results in a smoother ICU course and a shorter hospital stay, with higher risk of vascular injury. Shunt and Stent procedures have a good outcome for PA growth, somatic growth and survival.

\textit{Keywords:} Patent ductus arteriosus, Stent, Shunt, Pulmonary artery growth

1. Introduction

Surgery is the standard intervention in congenital heart diseases (CHD) with arterial duct dependent pulmonary circulation, known classically as Blalock-Taussig-Thomas shunt [1]. In 1988 Mullins et al. used expandable stents in dogs' pulmonary arteries (PAs) [2]. 3 years later, stents were used in human with CHD [3]. In 1992, Gibbs and his colleagues reported two cases of patent ductus arteriosus (PDA) stent implantation in CHD with duct dependent pulmonary circulation [4]. Both systemic to pulmonary shunt (Shunt) and PDA stent (Stent) are not complications free. We aimed to compare both procedures in the immediate course in the ICU for the hemodynamics, ventilation, infection and the length of stay. Furthermore, we followed those patients for the cumulative readmission days to hospital, PAs growth as well as the homogeneity of this growth and patient's growth.
2. Methods

Retrospectively we reviewed all infants under 3 months of age who were admitted to pediatric cardiac ICU after Stent or Shunt for initial palliation to maintain pulmonary blood flow. Patients who had an intervention to either PA branches at the first intervention or during follow-up were excluded. The study was approved by the Institutional Review Board (IRB). Patient consent was waived by IRB being a retrospective study.

All Shunt patients underwent median sternotomy with creation of the Shunt by Gortex® material [5]. Stent was mostly implanted through an arterial femoral access and rarely from a venous access to PA or aorta. Stents were performed under general anesthesia in the catheterization laboratory utilizing 4–7 French sized sheaths. Stents were 3.5–7 mm in diameter with a variable length to cover the entire arterial duct [6]. Occasionally prostaglandin E1 was stopped 6 hours prior to ductus stenting if PDA was large to minimize the risk of stent migration [7].

Both groups were compared for demographics, shock required emergent intervention (needed intervention within 6 hours from admission), size of PA branches (z score), the presence of pulmonary forward flow, track of repair to be on the single ventricle (SVR) or biventricular future repair (BiVR). SVR was considered when the patient is planned for future cavo-pulmonary isolation (Fontan operation). We compared the immediate ICU outcomes as well: inotropic score (IS) [8], positive pressure ventilation (PPV) days and the duration of the ICU and hospital stay.

Complications were recorded including hospital acquired infection, necrotizing enterocolitis (NEC) and the need for cardio-pulmonary resuscitation (CPR). Arterial or venous thromboses were confirmed by Doppler study after clinical suspicion (i.e. decreased limb perfusion, absence of pulsation or congestion).

All patients were followed till the second intervention or for one-year whichever earlier. Cardiac readmission to calculate the cumulative hospital days through the follow up period was documented. PAs growth was reviewed before intervention and at last follow-up. Ipsilateral PA branch was defined as the branch on the same side of the Stent or Shunt and the contralateral branch was defined as the branch on the other side. The ipsi:contralateral ratio was determined to observe the homogeneity of either sides PA branches growth (this ratio was not taken into consideration for patients with central Shunt), the more the ratio is closer to 1 the more the homogeneity of the PA branches [9]. Due to the lack of angiographic data from catheterization before Shunt, echocardiographic images have been utilized to calculate the Nakata index for quantification of PAs size [7,10]. Body surface area was calculated using Mosteller formula [11].

| Variables                        | Shunt (n = 110) | Stent (n = 77) | P value |
|----------------------------------|----------------|---------------|---------|
| Gender                           |                |               |         |
| Female                           | 48 (44%)       | 46 (60%)      | 0.7     |
| Male                             | 62 (56%)       | 31 (40%)      |         |
| Weight (kg)                      | 3.4 ± 0.8      | 3.2 ± 0.6     | 0.5     |
| Age (months)                     | 1.2 (0.7–2.3)  | 0.6 (0.3–1)   | <0.0001*|
| Size (mm)                        | 3.5 ± 0.6      | 4.3 ± 0.4     | <0.0001*|
| Emergency intervention           | 30 (36%)       | 1 (1.5%)      | <0.0001*|
| Pre-operative shock              | 8 (10%)        | 1 (1%)        | 0.04*   |
| RPA z                            | −1.4 (−2.9 to 0.2) | −1.3 (−2 to −0.1) | 0.7 |
| LPA z                            | −1.3 (−3 to 0.2) | −1.3 (−2.8 to 0) | 0.9 |
| Nakata index                     | 163 ± 91       | 146 ± 48      | 0.2     |
| Pulmonary forward flow           | 41 (49%)       | 30 (43%)      | 0.5     |
| Single ventricle repair track    | 63 (78%)       | 35 (52%)      | 0.0013* |

LPA: left pulmonary artery, RPA: right pulmonary artery, z: z score.
Body weight centiles and hemoglobin (Hb) levels (as a secondary indicator for the chronic hypoxia) were reviewed before procedure and at last follow-up. The increment of body weight centiles was calculated from the difference between initial and last weight percentile for age. The increment of Hb levels was calculated from the difference between initial and last Hb levels.

Mortality was reviewed in the early stage (less than 28 days from the procedure) and late mortality till one year after the procedure.

Data were expressed as numbers and percentages for categorical variables and as mean ± SD for continuous variables. Data that did not fit a normal distribution were expressed as medians and interquartile range (IQR). Continuous variables were compared using paired Student t-test or Mann-Whitney test for the nonparametric variables whenever needed, and categorical variables were compared using chi-square test or Fisher exact test whichever appropriate. Further sub-analyses were done checking the influence of SVR and/or emergent intervention on the outcome variables. A p value of less than or equal to 0.05 was considered statistically significant. We used SPSS statistics software Version 21 (IBM, Armonk, NY) for the analyses.

3. Results

We collected 187 patients over 9 years, 110 Shunt and 77 Stent. Shunt group were older 1.2 (0.7–2.3) months in comparison to Stent group 0.6 (0.3–1) months, p < 0.0001 but they have comparable weight 3.4 ± 0.8 vs 3.2 ± 0.6 kg, p 0.5. Four patients were excluded from follow up, 3 of them were from the Shunt group (2 had PA branches stenting and 1 had PA plasty). The fourth patient was from Stent group required Shunt and PA plasty due to desaturation. Shock that required emergent intervention was mainly in Shunt group. More patients of single ventricle repair track were subjected to Shunt. [Table 1].

Weight and PA branches size (indicated by Nakata index and z score) for both groups were comparable at the time of the procedure. [Tables 1 and 3].

Inotropic score (IS) 24 hours after intervention was higher in Shunt group vs Stent group 7.3 ± 2.2 and 1.1 ± 4.1 respectively, p < 0.0001. Shunt group had more positive pressure ventilation (PPV), ICU and hospital days. Sepsis occurred more in the Shunt group with 30 patients (27%) vs 5 patients (6%) in the Stent group (p 0.0003). [Table 2].

Sub-analysis comparing SVR vs BiVR patients was done. Both SVR and BiVR had similar PPV days 3 (1–8) vs 4 (0–8) p 0.9, ICU days 8 (4–18) vs 8 (3–18) p 0.9 and hospital days 23 (13–41) vs 22 (13–35) p 0.64.

Furthermore, we sub-analyzed the emergency vs elective cases. Patients required emergency intervention had more PPV days 6 (3–9) vs 2 (0–7) p 0.04 and more ICU days 11 (7–18) vs 7 (2–18) p 0.004 but they have similar hospital days 24 (16–54) vs 21 (12–35) p 0.3.

Arterial injury was more frequent in Stent group with 13 patients (17%) vs 5 patients (5%) in the Shunt group (p 0.005). There was no correlation between body weight and evidence of arterial injury. Weight was 3.14 ± 0.6 in those without arterial injury, 3.2 ± 0.6 in those with arterial injury. p 0.6.

Patients were followed for 7.5 (3–12) months and 6.2 (3.3–10.4) months in Shunt and Stent groups,

Table 2. Immediate outcome variables comparison.

| Variables                                | Shunt (n = 110) | Stent (n = 77) | P value |
|------------------------------------------|-----------------|----------------|---------|
| Inotropic score (12hrs)                  | 7.9 ± 7.6       | 0.6 ± 1.8      | <0.0001*|
| Inotropic score (24hrs)                  | 7.3 ± 7.2       | 1.1 ± 4.1      | <0.0001*|
| PPV days                                 | 5.5 (3–11)      | 1 (0–2)        | <0.0001*|
| ICU stay days                            | 13 (7–23)       | 4 (1–8)        | <0.0001*|
| Hospital stay days                       | 27 (18–52)      | 14 (8–26)      | <0.0001*|
| Oxygen saturation on admission           | 80.9 ± 10.7     | 87.3 ± 7.0     | 0.0001*|
| Oxygen saturation on discharge           | 83.3 ± 13.9     | 86 ± 10.2      | 0.19    |
| Intervention site thrombosis:           |                 |                |         |
| Arterial                                 | 5 (5%)          | 13 (17%)       | 0.005* |
| Venous                                   | 3 (3%)          | 7 (9%)         | 0.057  |
| Hospital acquired infections:           |                 |                |         |
| Sepsis                                   | 30 (27%)        | 5 (6%)         | 0.0003*|
| CAUTI                                    | 6 (5%)          | 4 (5%)         | 0.9    |
| NEC                                      | 3 (3%)          | 1 (1%)         | 0.5    |
| CPR                                      | 12 (11%)        | 5 (6%)         | 0.3    |

Hrs: hours, PPV: Positive Pressure Ventilation; CAUTI: Catheter Associated Urinary Tract Infection, NEC: Necrotizing enterocolitis. CPR: Cardio-pulmonary resuscitation.
respectively, \( p = 0.27 \). PA branches showed a tendency of a better growth at follow-up in the Stent group with Nakata 194 ± 97 vs 162 ± 110 in the Shunt group, \( p = 0.09 \). [Fig. 1]. However, ipsi:contralateral PA branch ratio was similar before either procedure, but more homogeneous growth was observed in patients after Stent procedure. [Table 3, Fig. 2]. Five patients from Shunt group required stenting the Shunt during follow up without PA branches intervention and still considered in the Shunt group.

Accumulative readmission hospital days during follow-up were similar between the groups. Changes in the hemoglobin levels and in the weight percentile for age from the procedure date till the last follow-up were not statistically different between groups [Table 3].

Early mortality within 28 days from the procedure was 9 (8%) in Shunt group and 2 (2.6%) in the Stent group, \( p = 0.1 \). Survival at one year was 87% and 95% for the Shunt and Stent group, respectively, \( p = 0.1 \). [Table 3, Fig. 3].

4. Discussion

Different approaches were introduced to improve outcome in patients with CHD presenting with

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Table 3. Comparison of follow-up outcome variables.

| Variables                        | Shunt (n = 110) | Stent (n = 77) | \( P \) value |
|----------------------------------|----------------|---------------|--------------|
| Follow-up duration               | 7.5 (3–12)     | 6.2 (3.3–10.4)| 0.27         |
| Nakata index \((\text{mm}^2/m^2)\) |                |               |              |
| Initial                          | 163 ± 91       | 146 ± 48      | 0.2          |
| Follow-up                        | 162 ± 110      | 194 ± 97      | 0.09         |
| Ipsi:contralateral ratio:        |                |               |              |
| Initial                          | 1 ± 0.2        | 1 ± 0.5       | 0.8          |
| Follow-up                        | 1.2 ± 0.4      | 1 ± 0.2       | 0.01*        |
| Readmissions hospital days       | 0 (0–9)        | 3 (0–14)      | 0.12         |
| Increment of Hb (g/l)*           | 22.6 ± 67      | 43 ± 93       | 0.2          |
| Increment of weight percentilec  | 3.6 ± 2.2      | 3.1 ± 1.6     | 0.2          |
| Mortality                        |                |               |              |
| ≤28 days                         | 9 (8%)         | 2 (2.6%)      |              |
| 29 days–12 months                | 5 (5%)         | 2 (2.6%)      | 0.1          |
| Total                            | 14 (13%)       | 4 (5%)        |              |

Hb: hemoglobin.

*a* Significant \( p \) value.

*b* Calculated as: last Hb - Initial Hb.

*c* Calculated as: Last weight percentile for age - Initial weight percentile.

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Fig. 1. Comparing the progression of Nakata index for pulmonary arteries at initial diagnosis and last follow-up for Shunt and Stent groups. Nakata index was maintained in Shunt group through follow-up period indicating acceptable growth. In Stent patients was higher over follow-up period indicating better growth.

Fig. 2. Comparing the ratio between intervention side and the other side (ipsi:contralateral ratio) at initial diagnosis and at last follow-up for Shunt and Stent groups, indicating similar homogeneity of the branch pulmonary arteries growth.
ductal-dependent pulmonary blood flow to enhance a homogeneous growth of both PA branches [5,9,12]. A multi-institutional review of more than 1200 neonates who had Shunt showed no difference in their outcome if surgery was done off vs on pump or if they ligated the PDA or if it was left opened [13]. Since 1992 when Gibbs and his colleagues introduced the ductal stenting as an alternative method to maintain pulmonary blood flow [4], the technique of deploying stents in the PDA has been advanced further and improved the clinical outcome in those patients over the following years [6,14,15].

In our study, we observed that the Shunt group had a more complicated post-operative course: Shunt patients had ten times higher IS score at 12 and 24 hours post procedure, triple PPV hours and double ICU and hospital days. Complications such as necrotizing enterocolitis and cardiac arrest that required CPR were found more frequently in the Shunt group though this was not statistically significant. More emergent intervention and SVR were noticed in Shunt patients but both factors did not increase hospital days when sub-analyzed separately. SVR did not influence the ICU course while emergency intervention increased PPV and ICU days. Sepsis was observed 4 times more in Shunt subjects which could be explained by the critical pre-Shunt presentation and longer staying days.

Stent patients, on the other hand, had more vascular injury especially arterial, which is a major morbidity that occurred in our population (17%). Due to this observation, we used to send small babies (less than 2.5 kg) for Shunt procedure. Hopefully smaller and smoother sheaths will be introduced in the market to minimize this complication. We elected to highlight this finding objectively, which was similarly described by other researchers recently with comparable rate to our result for arterial injury [16]. Our data did not show correlation between weight and arterial injury, that may be due to the small number of cases with arterial injury and the selection bias for children underwent Stent. We think that utilizing ultrasound for the vascular access along with smaller sheaths may indeed minimize such complications in the near future [17]. Moreover, a carotid artery cut-down is being utilized in small patients with an excellent outcome and less vascular complications [18]. Boucek et al. reviewed six studies comparing Shunt with Stent outcomes and described similar results, though vascular injury was not highlighted [19].

Further follow-up for near a year time showed us a tendency for better growth of PA branches in the Stent group, as indicated by the Nakata index, however, the Shunt group had also a fairly acceptable growth. Furthermore, there was a statistical difference in the ipsi:contralateral ratio for either PA branches but we do not think that this finding has a significant clinical impact on the outcome on those patients, as reported and seen in other papers as well [Table 3] [7,19–21], although some authors have highlighted a distortion of PA branches growth [9,22,23].

Mortality tended to be more in the Shunt group (13%) compared to (5%) in Stent group, p 0.1; similarly, other researchers have reported mortality for Shunt (10–36%) and Stent (7–18%) [Table 2] [24,25].

Our study is a retrospective study with high possibility of selection bias as many emergency cases underwent Shunt for initial palliation, which may complicate the comparison. Many subclinical cases of vascular injury are expected in this context, which requires a prospective study to indicate the significance and to follow the corresponding limb growth in a longitudinal fashion. We have used echocardiographic images to calculate the Nakata index for quantification of PAs size as catheterization data was not available for us before Shunt. However, some of the missing comparable catheterization data would be obtainable in a prospective observation.

5. Conclusions

The implantation of PDA stent in patients with duct dependent pulmonary circulation results in a smoother ICU course and a shorter hospital stay,
with higher risk of vascular injury. Shunt and Stent procedures have a good outcome for PA growth, somatic growth and survival.

Conflict of interest

No conflict of interest among the co-authors.

Funding statement

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Consent

Patient consent was waived by IRB being a retrospective study.

Author contribution

Conception and design of Study: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Omar Tamimi. Literature review: Ghassan A. Shaath, Ahmed Alomrani, Omar Tamimi. Acquisition of data: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Fahad Alhabsan, Mansour B. Almutairi. Analysis and interpretation of data: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Mohammed Fararjeh, Mohammad Allugmani, Fahad Alhabsan, Mansour B. Almutairi. Research investigation and analysis: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Mohammed Fararjeh, Mohammad Allugmani, Fahad Alhabsan, Mansour B. Almutairi. Data preparation and editing the manuscript critically for important intellectual contents: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Ahmed Alomrani, Omar Tamimi. Data collection: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Mohammed Fararjeh, Mohammad Allugmani, Fahad Alhabsan, Mansour B. Almutairi, Ahmed Alomrani, Omar Tamimi. Drafting of manuscript: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Mohammed Fararjeh, Mohammad Allugmani. Revising and editing the manuscript critically for important intellectual contents: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Ahmed Alomrani. Data preparation and presentation: Ghassan A. Shaath, Abdulraouf MZ. Jijeh, Mohammed Fararjeh, Mohammad Allugmani, Ahmed Alomrani. Supervision of the research: Ghassan A. Shaath, Omar Tamimi. Research coordination and management: Ghassan A. Shaath, Abdulraouf MZ. Jijeh.

References

[1] Blalock A, Taussig HB. Landmark article May 19, 1945: the surgical treatment of malformations of the heart in which there is pulmonary stenosis or pulmonary atresia. By Alfred Blalock and Helen B. Taussig. J Am Med Assoc 1984;251(16): 2123–38. https://doi.org/10.1001/jama.251.16.2123.

[2] Mullins CE, O’Laughlin MP, Vick 3rd GW, Mayer DC, Myers TJ, Kearney DL, et al. Implantation of balloon-expandable intravascular grafts by catheterization in pulmonary arteries and systemic veins. Circulation 1988;77(1): 188–99. https://doi.org/10.1161/01.cir.77.1.188.

[3] O’Laughlin MP, Perry SB, Lock JE, Mullins CE. Use of endovascular stents in congenital heart disease. Circulation 1991;83(suppl 2):239–32. https://doi.org/10.1161/01.cir.83.6.1923.

[4] 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(3):240–5. https://doi.org/10.1136/hrt.67.3.240.

[5] Williams JA, Bansal AK, Kim BJ, Nwakanma LU, Patel ND, Seth AK, et al. Two thousand Blalock-Taussig shunts: a six-decade experience. Ann Thorac Surg 2007;84(4):2070–5. https://doi.org/10.1016/j.athoracsur.2007.06.067. discussion 5-1.

[6] Schneider M, Zartner P, Sidiropoulos A, Konertz W, Haushofer G. Stent implantation of the arterial duct in newborns with duct-dependent circulation. Eur Heart J 1998; 19(9):1401–9. https://doi.org/10.1053/euhj.1998.0977.

[7] Santoro G, Capozzi G, Caianiello G, Palladino MT, Marrone C, Farina G, et al. Pulmonary artery growth after palliation of congenital heart disease with duct-dependent pulmonary circulation: arterial duct stenting versus surgical shunt. J Am Coll Cardiol 2009;54(21):2180–6. https://doi.org/10.1016/j.jacc.2009.07.043.

[8] Gais MG, Gurney JG, Yen AH, Napoli ML, Gajarski BJ, Ohye RG, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. Pediatr Crit Care Med 2010;11(2):234–8. https://doi.org/10.1097/PCC.0b013e3181d880fc.

[9] Batra AS, Starnes VA, Wells WJ. Does the site of insertion of a systemic-pulmonary shunt influence growth of the pulmonary arteries? Ann Thorac Surg 2005;79(2):636–40. https://doi.org/10.1016/j.jathoracsur.2004.07.062.

[10] Nakata S, Imai Y, Takashani Y, Kurosawa H, Tsuchiya K, Nakazawa M, et al. A new method for the quantitative standardization of cross-sectional areas of the pulmonary arteries in congenital heart diseases with decreased pulmonary blood flow. J Thorac Cardiovasc Surg 1984;88(4):610–9.

[11] Mosteller RD. Simplified calculation of body-surface area. N Engl J Med 1987;317(17):1098. https://doi.org/10.1056/NEJM198710223171717.

[12] 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(1):106–12. https://doi.org/10.1016/j.jtcvs.2010.10.033.

[13] 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(2):642–51. https://doi.org/10.1016/j.jathoracsur.2011.02.030. discussion 51-2.

[14] Gewillig M, Boshoff DE, Jens D, Mertens I, Benson LN. Stenting the neonatal arterial duct in duct-dependent pulmonary circulation: new techniques, better results. J Am Coll Cardiol 2004;43(1):107–12. https://doi.org/10.1016/j.jacc.2003.08.029.

[15] Alwi M. Stenting the ductus arteriosus: case selection, technique and possible complications. Ann Pediatr Cardiol 2008;1(1):38–45. https://doi.org/10.4103/0974-2069.41054.

[16] Ratnayaka K, Nageotte SJ, Moore JW, Guyon PW, Bhandari K, Weber RI, et al. Patent ductus arteriosus stenting for all ductal-dependent cyanotic infants: waning use of blalock-taussig shunts. Circ Cardiovasc Interv 2021; 14(3):e009520. https://doi.org/10.1161/CIRCINTERVENTIONS.120.009520.

[17] Bonnet C, Agnoletti G, Largen E, Boujdjemine Y, Szczepanski I, Bonnet D, et al. Use of 3 French catheters for diagnostic and interventional procedures in newborns and small infants. Arch Mal Coeur Vaiss 2004;97(5):495–500.

[18] Qureshi AM, Goldstein BH, Glatz AC, Aggarwal V, Ligon RA, et al. Classification scheme for ductal morphotype in cyanotic patients with ductal dependent pulmonary blood flow and association with outcomes of patent ductus arteriosus stenting. Cathet Cardiovasc Interv.
Boucek DM, Qureshi AM, Goldstein BH, Petit CJ, Glatz AC. Blalock-Taussig shunt versus patent ductus arteriosus stent as first palliation for ductal-dependent pulmonary circulation lesions: a review of the literature. Congenit Heart Dis 2019;14(1):105–9. https://doi.org/10.1111/chd.12707.

Alwi M, Choo KK, Latiff HA, Kandavello G, Samion H, Mulyadi MD. Initial results and medium-term follow-up of stent implantation of patent ductus arteriosus in duct-dependent pulmonary circulation. J Am Coll Cardiol 2004;44(2):438–45. https://doi.org/10.1016/j.jacc.2004.03.066.

Santoro G, Capozzi G, Capogrosso C, Mahmoud HT, Gaio G, Palladino MT, et al. Pulmonary artery growth after arterial duct stenting in completely duct-dependent pulmonary circulation. Heart 2016;102(6):459–64. https://doi.org/10.1136/heartjnl-2015-308493.

McMullan DM, Permut LC, Jones TK, Johnston TA, Rubio AE. Modified Blalock-Taussig shunt versus ductal stenting for palliation of cardiac lesions with inadequate pulmonary blood flow. J Thorac Cardiovasc Surg 2014;147(1):397–401. https://doi.org/10.1016/j.jtcvs.2013.07.052.

Ishikawa S, Takahashi T, Sato Y, Suzuki M, Murakami J, Hasegawa Y, et al. Growth of the pulmonary arteries after systemic-pulmonary shunt. Ann Thorac Cardiovasc Surg 2001;7(6):337–40.

Bentham JR, Zava NK, Harrison WJ, Shauq A, Kalantre A, Derrick G, et al. Duct stenting versus modified blalock-taussig shunt in neonates with duct-dependent pulmonary blood flow: associations with clinical outcomes in a multicenter national study. Circulation 2018;137(6):581–8. https://doi.org/10.1161/CIRCULATIONAHA.117.028972.

Glatz AC, Petit CJ, Goldstein BH, Kelleman MS, McCracken CE, McDonnell A, et al. Comparison between patent ductus arteriosus stent and modified blalock-taussig shunt as palliation for infants with ductal-dependent pulmonary blood flow: insights from the congenital catheterization research collaborative. Circulation 2018;137(6):589–601. https://doi.org/10.1161/CIRCULATIONAHA.117.029987.