ORIGINAL ARTICLE

A new perspective on aortic pressure for transcatheter closure of patent ductus arteriosus in the pediatric population

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Editorial
by Bitar and Bulbul

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ABSTRACT

Background: Hemodynamic assessment is not routinely performed when closing a patent ductus arteriosus (PDA). Significant PDA flow causes a drop in the aortic pressure distal to the shunt. Closure of PDA should increase distal systemic blood flow and significantly elevate distal aortic pressure, changing the systolic pressure gradient (ΔP) between the proximal and distal aorta. However, this phenomenon has yet to be studied.

Aims: This study aimed to analyze the influence of PDA closure on the difference of the aortic pressures proximal versus distal to the shunt.

Methods: A registry included 50 consecutive children who had undergone PDA closure in the years 2022–2023. A simplified hemodynamic assessment was regularly performed by measuring blood pressure in the ascending and descending aorta, with a ΔP calculated before and after the procedure.

Results: Following PDA closure, ΔP between the ascending and descending aorta improved in 54% of patients, remained unchanged in 16%, and worsened in 30%. Abnormal mean (SD) ΔP was observed before the procedure (85.06 [10.22] mm Hg vs. 83.72 [10.47] mm Hg; $P = 0.004$) with a marked improvement after the intervention (80.64 [9.82] mm Hg vs. 79.72 [9.9] mm Hg; $P = 0.24$). A significant ΔP improvement was observed after PDA closure ($P = 0.02$).

Conclusions: Simple pressure measurements may help to understand the hemodynamic changes during PDA closure. Restoration of physiological pressure in the distal and proximal aorta was observed in most patients but not all. Further studies are needed to better understand the hemodynamics during PDA closure.

Key words: hemodynamic assessment, patent ductus arteriosus, systolic blood pressure gradient

INTRODUCTION

Patent ductus arteriosus (PDA) is a common congenital heart disease, accounting for 10%–15% of all lesions [1]. Since Porstmann described the first successful transcatheter PDA closure in 1966 [2, 3], the procedure has been routinely performed in recent decades. Various occlusion devices were developed, such as the Rashkind umbrella [4], the Sideris adjustable button device [5], coil devices, and the latest one — the Amplatzer Duccluder type II, released in 2007 [6, 7].

The indications for closure include PDA with a left-to-right shunt without signs of irreversible pulmonary hypertension, except silent ones [8–10]. The patient's qualification for PDA

WHAT'S NEW?

Currently, the qualification of patients for patent ductus arteriosus (PDA) closure is based mainly on echocardiographic findings rather than more precise invasive measurements taken during cardiac catheterization. The invasive procedure involves duct closure without additional hemodynamic evaluation. In this article, we propose a simple and rapid transarterial technique to evaluate the hemodynamic changes accompanying the closure of PDA done during the same procedure. To the best of our knowledge, this is the first study to routinely assess the systolic blood pressure difference between the ascending and descending aorta before and after PDA closure. This may contribute to a better understanding of hemodynamic changes during the procedure and assessing return to physiological conditions immediately after closure.

closure is based mainly on echocardiographic examination and angiographic contrast study [11].

Hemodynamic changes in the circulation associated with PDA are significant. They reflect a paradoxical reduction in systemic flow despite increased cardiac output due to the shunting of blood from the systemic to pulmonary circulation through a patent duct, causing remodeling of the left ventricle and eventually heart failure. If the condition persists over the long term, aside from pulmonary hypertension, it may result in systemic complications, including cardiorenal syndrome [1–13]. This so-called "hemodynamic paradox" is well described in the literature [14–15]. Immediately after duct closure, hemodynamic conditions change significantly; all the blood previously shunting to the pulmonary circuit remains in the systemic circulation, while the pulmonary circulation gets disconnected from the systemic one. Therefore, hemodynamic changes related to the duct closure can be observed. Blood pressure can be easily recorded both proximal and distal to the PDA (in the ascending and descending aorta) before and immediately after PDA closure.

Accurate hemodynamic assessment during PDA closure can be obtained by detailed cardiac catheterization, which is rarely performed in routine practice. The significance of simple aortic pressure measurements was not sufficiently studied.

We sought to analyze the proximal (ascending aorta) and distal (descending aorta) aortic pressures recorded before and after PDA closure.

METHODS

We included all children who underwent transcatheter percutaneous closure of PDA at the Department of Pediatrics and Pediatric Gastroenterology with Pediatric Cardiology Subdivision in Rzeszow from February 2022 until May 2023. Selected data from their medical records, echocardiographic findings, and hemodynamic examinations were analyzed. Indications for intervention included the presence of an audible murmur at the upper left sternal border or left infraclavicular area in physical examination and a body weight of more than 6 kg at the time of the procedure. The local ethics committee approved the study.

The transcatheter PDA closure procedures were performed at the catheterization laboratory under fluoroscopic guidance. All patients underwent the procedure under general anesthesia, and all interventions were performed *via* the retrograde arterial transfemoral approach. The common femoral artery was canulated using a 4F or 5F introducer. After the non-invasive measurement of arterial blood pressure on the upper right hand, the first stage of the procedure consisted of a simplified hemodynamic assessment, including measurements of ascending and descending aorta pressures with the calculation of the systolic pressure gradient (ΔP) and left ventricular systolic and end-diastolic pressures. ΔP was calculated as a difference between systolic pressure in the ascending and descending aorta. The mean pulmonary artery pressure was measured through the duct before its occlusion.

After hemodynamic evaluation, an aortogram was performed in the straight lateral projection (LAT 90°) to determine the size and shape of the PDA. Duct morphology was categorized according to Krichenko's classification [16]. Then, a ductal occluder (Amplatzer™ Duct Occluder II — ADO II, Abbott, US) was implanted to close the PDA. Conclusion angiography was performed by placing a pigtail catheter into the aortic arch to confirm the final result of the procedure. The final hemodynamic evaluation included pressure measurements in the ascending and descending aorta with ΔP calculation. In a healthy person, the systolic blood pressure in the ascending aorta is slightly lower compared to the descending aorta, i.e., the calculated ΔP is negative. That is why the physiological gradient was defined as a higher systolic blood pressure in the descending aorta than in the ascending aorta. In contrast, the pathological gradient was defined as a systolic blood pressure in the descending aorta lower than or equal to that in the ascending aorta. The final non-invasive blood pressure measurement on the upper right hand was performed at the end.

The following clinical data were collected: patient demographics, clinical signs and symptoms, transthoracic echocardiography results (left atrium-to-aortic root ratio, right ventricular systolic pressure, and left pulmonary artery diastolic flow velocity), hemodynamic assessment before and after ductal closure, and PDA-related data (length, type, and the narrowest diameter).

Statistical analysis

Continuous variables were presented as means and standard deviations (SD) for normally distributed data

Table 1. Hemodynamic parameters before and after patent ductus arteriosus closure

Variables	Before procedure (n = 50)	After procedure (n = 50)	*P*-value
MPAP, mm Hg, mean (SD)	16.48 (3.53)	Not available	–
LVSP, mm Hg, mean (SD)	90.06 (12.55)	Not available	–
LVEDP, mm Hg, median (IQR)	5.5 (1.25–10)	Not available	–
Ao asc syst, mm Hg, mean (SD)	85.06 (10.22)	80.64 (9.82)	<0.001
Ao asc diast, mm Hg, median (IQR)	47 (42–54.75)	47 (42–51)	0.08
Ao desc syst, mm Hg, mean (SD)	83.72 (10.47)	79.72 (9.9)	0.002
Ao desc diast, mm Hg, mean (SD)	48.94 (8.12)	47.58 (7.92)	0.10
Ao mean, mm Hg, median (IQR)	65 (59.25–71)	61.5 (57–67)	0.003
RR syst, mm Hg, mean (SD)	99.12 (16.08)	89.94 (13.11)	<0.001
RR diast, mm Hg, mean (SD)	56.96 (12.76)	51.2 (11.48)	<0.001

Abbreviations: Ao asc diast, ascending aorta diastolic pressure; Ao asc syst, ascending aorta systolic pressure; Ao desc diast, descending aorta diastolic pressure; Ao desc syst, descending aorta systolic pressure; Ao mean, mean aortic pressure; LVEDP, left ventricle end-diastolic pressure; LVSP, left ventricle systolic pressure; MPAP, mean pulmonary artery pressure; RR syst, non-invasive systolic blood pressure; RR diast, the non-invasive diastolic blood pressure

and as medians and interquartile ranges (IQR) for data with non-normal distribution. Categorical variables and ranges were presented as numbers (percentages). Analysis was conducted using R software version 4.3.1. The frequency of physiological gradients before and after PDA was compared using McNemar's test, and all the other differences were compared with a t-test or Wilcoxon test, depending on the distribution. The normality of all tested distributions was assessed with the Shapiro–Wilk test. A *P*-value less than 0.05 was considered statistically significant for all tests.

RESULTS

A total of 50 consecutive patients who underwent the transcatheter PDA closure between February 2022 and May 2023 were enrolled.

The study population had a median (IQR) age of 3.86 (2–5.68) years. There were slightly more females than males, 29 (58%) vs. 21 (42%). During physical examination, a systolic ejection murmur was detected in 49 (98%) of the patients, and only one patient (2%) had a continuous "machinery" murmur below the clavicle. The anatomical variability of PDA was as follows: 34 patients had conical, 3 had complex, 10 had elongated, and 3 had tubular PDA types. All participants received the Amplatzer™ Duct Occluder II. Implantation success was achieved in all patients.

All hemodynamic parameters measured before and after the PDA closure procedure are summarized in Table 1.

The hemodynamic assessment showed that 11 (22%) children had elevated mean pulmonary artery pressure, defined as an increase to 20 mm Hg or more. Among the study participants, four patients showed signs of left ventricular diastolic dysfunction (LVEDP), described as an increase in LVEDP ≥12 mm Hg.

We observed statistically significant differences in systolic blood pressure before and after the procedure in both the ascending and descending aorta. At the same time, there were no such differences in diastolic blood pressure measured simultaneously at the same site. Additionally, we noticed a significant difference in mean arterial pressure measured before and after the procedure in the ascending aorta.

In our study, we observed that in PDA patients, systolic aortic pressure in the descending aorta was lower than in the ascending aorta, and ΔP was greater than 0 mm Hg. Specifically, before the procedure, the mean (SD) systolic pressure in the ascending aorta was higher compared to the descending aorta (85.06 [10.22] mm Hg vs. 83.72 [10.47] mm Hg; *P* = 0.004), while such a difference was not significant post-procedure (80.64 [9.82] mm Hg vs. 79.72 [9.9] mm Hg; *P* = 0.24). There was a trend towards a decrease in the pressure gradient after the procedure compared to the pre-procedure measurements. Specifically, the median (IQR) ΔP decreased from 1.54 (0–4) mm Hg to 0.92 (–2 to 2.75) mm Hg; *P* = 0.06. Of 50 patients in the study, ΔP between the ascending and descending aorta improved (became negative) in 27 participants (54%) after PDA closure. No change was observed in 8 patients (16%), while a worsening (the systolic gradient became more positive) was observed in 15 patients (30%). Figure 1 provides a schematic representation of the alteration in ΔP between the ascending and descending aorta following PDA closure.

We compared ΔP between the ascending and descending aorta before and after the procedure. Our observation showed that the pathological gradient was often normalized after the procedure. We also noted that the physiological (normalized) gradient was observed in more patients after PDA closure than before. This difference was statistically significant (*P* = 0.02), as shown in Figure 2.

DISCUSSION

The pressure wave reflection arises from any discontinuity in the elastic properties along the arterial tree where there is a change or mismatch in impedance [17]. In the general population, in an average aortic tree, the major reflection point, which represents the integrated reflection of the pressure wave, is located in the aortic bifurcation region [17, 18]. Therefore, under physiological conditions, systolic blood pressure at the descending aorta is higher than at the ascending aorta because the descending aorta is closer to

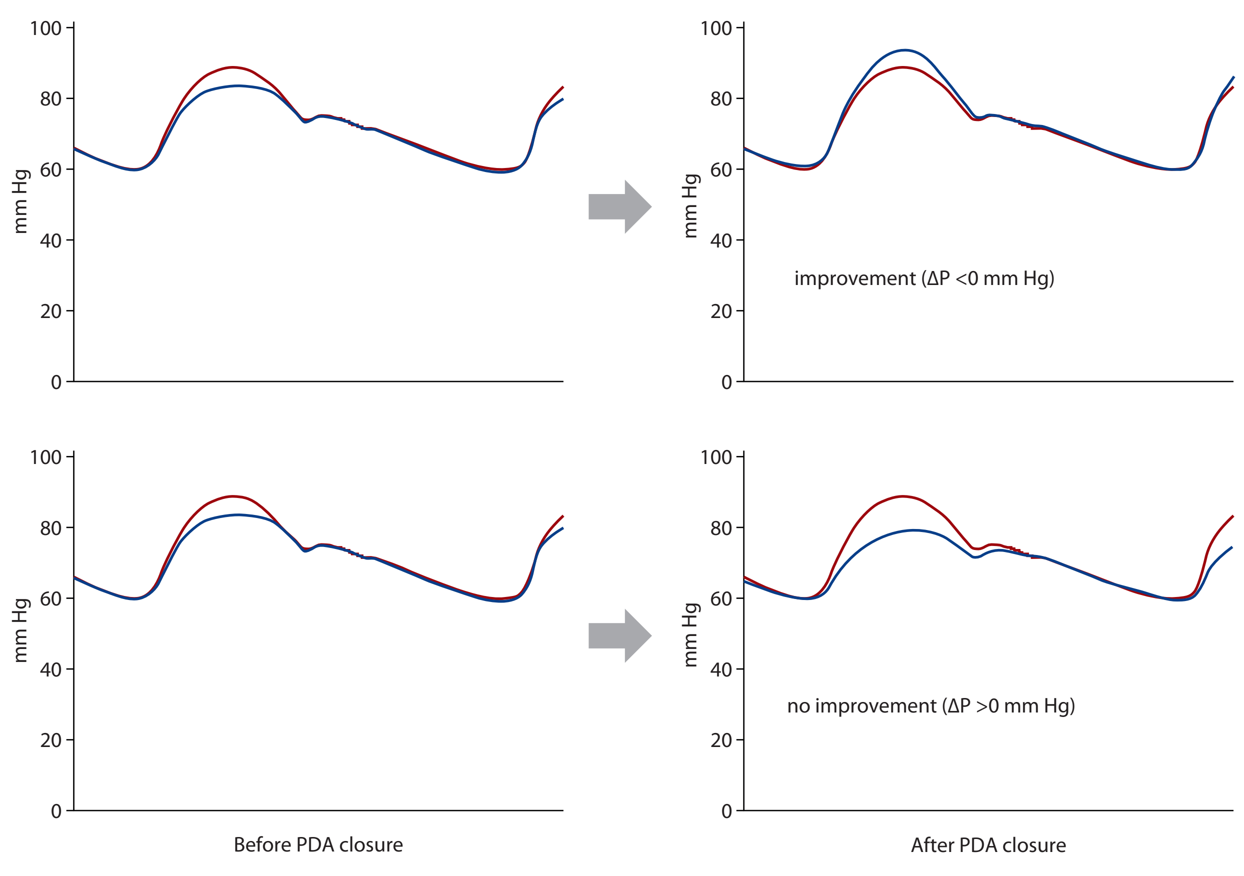

Figure 1. Schematic representation of the gradient change between the ascending and descending aorta after patent ductus arteriosus (PDA) closure. The red line represents the ascending aortic pressure, while the blue line represents the pressure in the descending aorta. Scheme A shows an improvement in the pressure gradient after PDA closure (ΔP became negative), while scheme B shows a worsening (ΔP became more positive)

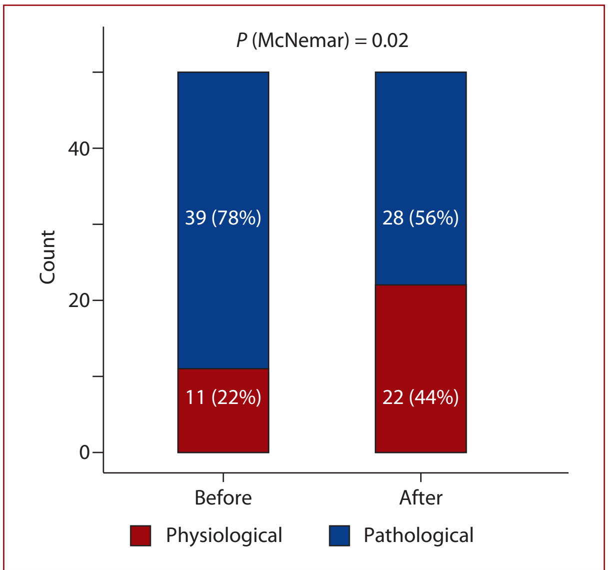

Figure 2. Patients with physiological and pathological aortic pressure gradients before and after patent ductus arteriosus closure. Physiological gradient means the ascending aorta systolic blood pressure is lower than the descending aorta systolic blood pressure; pathological gradient means the ascending aorta systolic blood pressure is not lower than the descending aorta systolic blood prebssure

the bifurcation than the ascending aorta, and the distance that reflected waves must cover from the aortic bifurcation to the descending aorta is shorter [18]. The reflected wave returns to the descending aorta and adds to systole, enhancing it and thus increasing pressure momentarily. On the other hand, until adolescence, higher extensibility and lower stiffness were observed under physiological conditions in the proximal part of the thoracic aorta. In contrast, the situation is the opposite in the distal parts of the aorta and the peripheral arteries [17], which also affects the increase in systolic pressure in the distal parts of the aorta. In our study, we observed the opposite situation, namely, in patients before PDA closure, invasively measured systolic blood pressure in the ascending aorta was significantly lower than in the descending aorta ($P = 0.004$). Thus, ΔP between the ascending and descending aorta was pathological (≥0 mm Hg). The situation improved notably immediately after duct closure, and ΔP became negative, as in physiological conditions (<0 mm Hg). Accordingly, before the intervention, 78% of patients had a pathological ΔP, and 22% had a physiological one, while after the intervention, these proportions were distributed as 56% and 44% of patients, respectively, $P = 0.02$. The observed "pathological" ΔP phenomenon can be explained by the fact that in the case of a persistent connection between the pulmonary and systemic circulations with a PDA, some blood "leaks" into the pulmonary circulation, thus escaping from the systemic circulation and reducing the blood volume just below the duct [15]. Despite increased cardiac output due to increased preload, the volume of blood reaching the descending aorta was significantly decreased. This phenomenon is known as the "hemodynamic paradox" [14, 15]. On the other hand, it is well known that blood pressure is regulated by a balance of the cardiac output and peripheral vascular resistance [19]. Considering the abovementioned pathophysiological mechanisms, the reduced systolic blood pressure in the descending aorta compared to the ascending aorta in PDA patients is completely understandable. As shown in this study, the situation changes immediately after successful duct closure. The systolic gradient between the ascending and descending aorta tends to be more physiological. Thus, this easy-to-obtain parameter can serve as a measure of hemodynamic improvement and marker of the effectiveness of PDA closure.

Nevertheless, despite successful PDA occluder implantation, ΔP did not always improve after the procedure. This can be explained by the protrusion of the occluder disc into the aortic lumen at the PDA site, resulting in aortic narrowing and an increase in the systolic pressure gradient between the ascending and descending aorta. According to Masri et al. [20], the rate of aortic protrusion was reported in 16% of patients after ADO II occluder implantation. However, this did not result in clinically significant coarctation of the aorta. On the other hand, an implanted occluder in the descending aorta generates an extra pressure wave reflection that travels backward toward the ascending aorta, thus enhancing systolic pressure [17, 18].

During our study, we observed a significant decrease in systolic blood pressure in both the ascending and descending aorta following the procedure compared to the baseline measurements. Additionally, there was a reduction in mean pressure, but no corresponding decrease was observed in diastolic blood pressure. Blood pressure is a dynamic variable that constantly changes during anesthesia. It reflects rapid changes in physiology that occur at the beginning of anesthesia. Factors that contribute to these changes include alterations in ventilation, administration of intravenous fluids and anesthetic drugs, surgical stimuli, and the response of anesthesia providers to these changes [21, 22]. Sottas et al. [23] reported that children's systolic and mean blood pressure drops significantly during anesthesia, particularly in infants and newborns. According to available literature, the prevalence of intraoperative hypotension varies from 5% to 99%, depending on the definition used [24].

Our study found no evidence of left ventricular diastolic dysfunction or elevated mean pulmonary artery pressure, in contrast to more recent literature [25, 26]. The reason for this may be the duct size, with its median (IQR) of 2.0 (1.7–2.3) mm, which was considered moderate according to the classification proposed by McNamara et al. [27]. Therefore, there was no excessive pulmonary overload, and pulmonary hypertension was not observed.

It is important to acknowledge several limitations of this study. First, the small sample size of the study should be noted. Second, the study was conducted at a single center. Additionally, only one type of occluder was utilized to seal the PDA. Finally, it should be noted that a complete hemodynamic assessment was not conducted, making a comparison of pulmonary and systemic flows impossible. Further investigations are required to complete the data.

CONCLUSIONS

Routine assessment of basic hemodynamic parameters, such as invasive pressure measurement in the ascending and descending aorta, provides information about the pressure change related to PDA closure. It may help understand hemodynamic changes related to the procedure. In addition to angiographic assessment, the systolic pressure gradient shift between the ascending and descending aorta after PDA closure can be used as another indicator of restoration of hemodynamic conditions to their physiological range. However, this finding warrants further investigation in subsequent studies.

Article information

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