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ORIGINAL ARTICLE

Accuracy of Routine 2D Echocardiography to Estimate Patent Ductus Arteriosus Type and Dimension and Predict Device Selection for Successful PDA Occlusion

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Abstract

Background: **Assessment of the shape and dimensions of PDA is usually done angiographically and in the majority of cases need arterial access.**

Our aim was to evaluate the value of routine 2 D echocardiography (ECHO) in predicting type, dimensions of PDA and to anticipate device size to be used during the intervention.

Material and methods: **The charts of all patients who underwent transcatheter closure of PDA between January 2015 and December 2020 were reviewed. Their pre-procedure ECHO and catheterization details at the time of device closure were analyzed.**

Results: **Total of 139 patients were reviewed and 8 were excluded because of lack of adequate echocardiographic or angiographic images. The mean age and weight of the study population were 2.6 ± 2.5 years (range 0.2−14 years) and 11.2 ± 7.8 kg (range: 1.5−57 kg), respectively. There was no statistically significant difference in PDA narrowest diameter ($p = 0.99$) and predicted device type ($p = 0.54$) between Echo and angiography. Echo slightly overestimated PDA length ($p = 0.01$) and aortic ampulla dimension ($p = 0.047$), while morphology of PDA was correctly identified in the majority of cases (82%).**

Conclusions: **Pre-procedure echocardiography correlates well with angiographically obtained measurements and hence can be used to estimate PDA diameter, shape and guide device decide selection. Routine echocardiography can be used successfully to plan the intervention and in some cases to guide transcatheter closure.**

Keywords: Patent ductus arteriosus, Echocardiographic guidance, Comparison echocardiography and angiography, Transcatheter closure

1. Introduction

Transcatheter device closure (TCC) of patent ductus arteriosus (PDA) is currently the treatment of choice for PDA occlusion across all ages [1]. The morphology of PDA is quite variable both with regard to its shape and dimensions which have procedural implications for TCC [2]. Accordingly, a wide variety of devices of different shapes and sizes have been developed to achieve successful occlusion of different PDA types. Comprehensive assessment of the shape and dimensions of the PDA, including diameter of ductal ampulla, length, and narrowest PDA diameter at its insertion into the pulmonary artery, are essential to determine the feasibility for device closure and select the

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appropriate device type and size without causing obstruction to flow in the aorta or left pulmonary artery [2,3]. This is done in the cardiac catheterization laboratory by reviewing the images obtained on aortic angiography. The PDA is well profiled on aortic angiography but at the cost of exposure to radiation and occasionally, especially for large PDA, more than one angiogram is required to correctly profile the PDA anatomy. However, approximately two decades ago, Ramaciotti C et al. (2002) showed that in majority of the cases, PDA dimensions can be reliably obtained using two dimensional and color Doppler echocardiography [4].

Recently, transthoracic echocardiography (TTE) guided device closure of the PDA has been explored as an attractive option as it avoids radiation exposure to the patient and the operator, in addition it reduces contrast administration to the patient. The results of some case series reporting closure of PDA under TTE guidance in children and adult patients [5–8] are encouraging. Recently this has been also noticed in extremely low birth weight infants [9–11]. Despite these reports, angiographic delineation of PDA morphology and its dimensions remains a central step in most centers to select an appropriate device.

Our aim was to evaluate the value of pre-procedure routine 2 D echocardiography to predict type and dimensions of PDA and to anticipate device size to be used during the intervention.

2. Methods and patients

In a retrospective fashion, all patients who underwent attempted device closure of PDA at our institution from January 2015 to December 2020 constituted the study population. Their TTE prior to the device closure of PDA was compared with the aortic angiograms at the time of device closure of the PDA retrospectively. Details of the devices used to occlude the PDA were obtained from the procedure note.

2.1. Exclusion criteria

Inadequate echocardiographic or angiographic images to reliably measure PDA dimensions. Patients with less than 1.5 kg body weight or premature babies. Patients with duct dependent lesions and PDA with elevated pulmonary vascular resistance.

2.2. Echocardiography

All echocardiographic studies were performed using IE33; Philips Medical Systems, (Eindhoven, The Netherlands). The 2D and color Doppler image loops obtained from the high left parasternal view (ductal view) were reviewed by a senior pediatric cardiologist blinded to the findings of the catheterization procedure. The best frame clearly delineating the anatomy of the PDA and its connections with both the aorta and the pulmonary artery was selected. Often it was a combination of 2 D echo image and color Doppler (Fig. 1a). We classified the PDA based on its morphology using a very modified Krichenko classification "conal, conal small, tiny, convex (aortic ampulla longer than length of PDA), window type, tubular, and elongated" [2,3]. The diameter of the ductal ampulla at the aortic end, its length and the narrowest PDA diameter at the pulmonary end were measured using electronic calipers available in the Xcelera Cardiology Information Management, Philips, The Netherlands (Fig. 1b,c).

Abbreviation

PDA	Patent ductus arteriosus
Echo	2D-echocardiography
TCC	Transcatheter device closure
ADO I and II	Amplatzer Duct Occluder

2.3. Aortic angiogram

Venous and arterial access were obtained in most cases. Aortic angiograms were performed as a power injection using either a pigtail or multipurpose catheter with cameras in straight lateral and anterior posterior position. If the PDA could not be clearly delineated, a right anterior oblique view was performed to visualize it. The angiograms were reviewed to select the frame best defining the anatomy of the PDA mostly in the straight lateral projection. The shape of the PDA and PDA dimensions performed using electronic calipers as shown in (Fig. 2a,b,c) were recorded. Devices used to close the PDA were Amplatzer duct occluder I or II (ADO I, ADO II) and detachable coils of different diameters.

2.4. Comparison of echocardiographic and angiographic findings and choice of device selection was performed

For each case, the type of PDA established on echocardiography was compared with that noted on angiography. Similarly, the PDA dimensions; aortic diameter, length of the PDA, and narrowest diameter measured with the two modalities were compared. An experienced investigator (MOG), blinded to

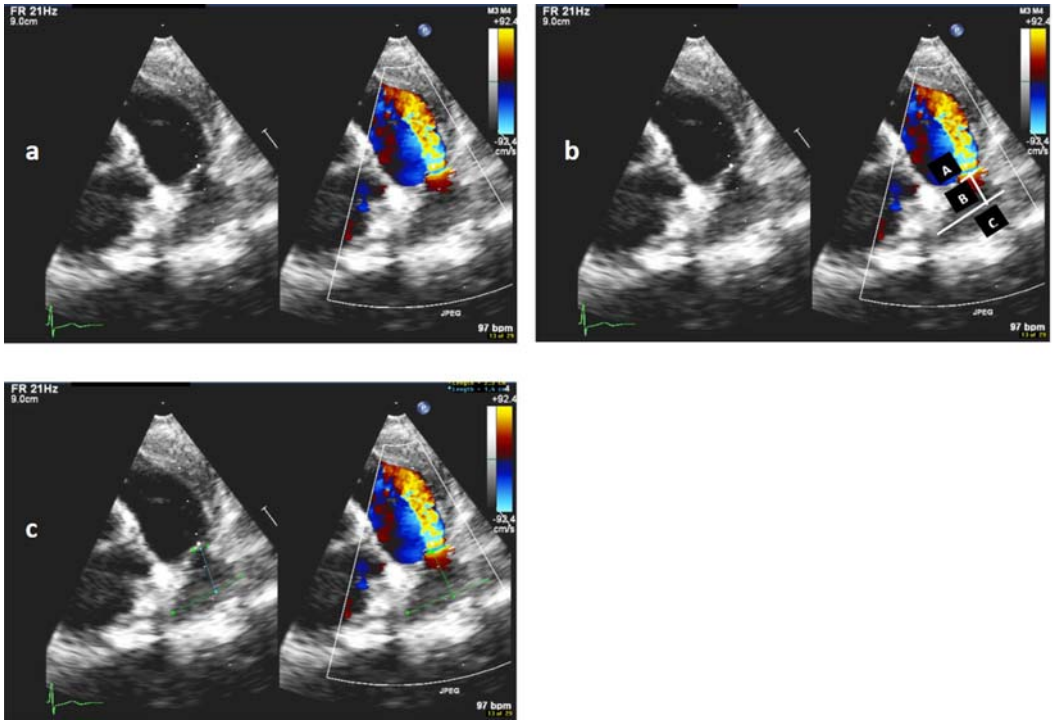

Fig. 1. Measurement of PDA dimensions by TTE. (1a) Color compare image in high parasternal view showing PDA. (2a) PDA measurements: (A) PDA narrowest diameter at pulmonary end (B) Length of the PDA and (C) diameter of the PDA at aortic end. (3a) Actual PDA measurements are shown.

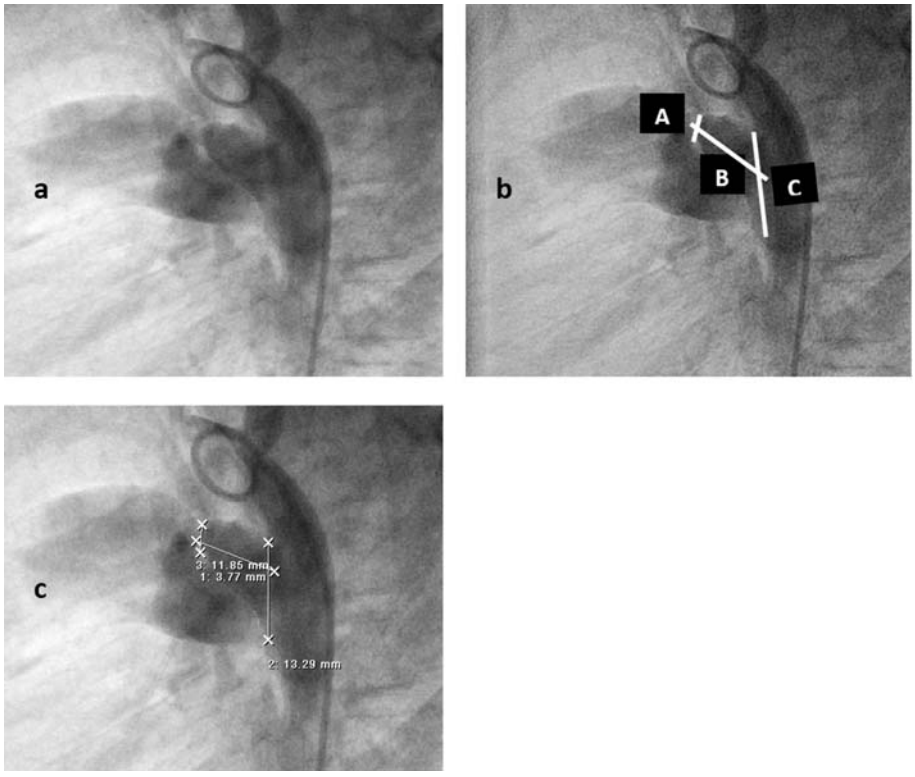

Fig. 2. Measurement of PDA dimensions by angiography in straight lateral projection. (1a) Image selection for measuring the PDA in lateral view. (2a) PDA Measurements: (A) PDA narrowest diameter at pulmonary end (B) Length of the PDA and (C) diameter of the PDA at aortic end. (3a) Actual PDA measurements are shown.

catheterization data, reviewed the morphology and dimensions of each PDA on echocardiography and predicted the type and size of the PDA device suitable to successfully occlude the given PDA. Another experienced investigator (ZA) reviewed the PDA morphology and dimensions on angiograms of all patients and recorded the device choice and size based on angiographic findings (Fig. 3a,b).

2.5. Statistical analysis

Descriptive statistics were used to report continuous variables including means and standard deviations. The echocardiographic PDA dimensions at the ampulla, pulmonary end and length were compared to angiogram dimensions using a two tailed Student's t test. P value of <0.05 was considered statistically significant. In addition, agreement between the two modalities was evaluated by Bland–Altman plot analysis using 95% confidence intervals [12]. Qualitative variables between echocardiography and angiography such as the PDA shape and device type were compared using Chi square test.

3. Results

Total of 139 patients were reviewed and 8 were excluded because of lack of adequate echocardiographic or angiographic images. The mean age and weight of the study population were 2.6 ± 2.5 years (range 0.2–14 years) and 11.2 ± 7.8 kg (range: 1.5–57 kg) respectively. Catheterization procedures were performed exclusively using transvenous access in 33 (29%) patients. In three patients the device or coil embolized (2.3%) but was retrieved successfully and the PDA was closed with a larger device.

3.1. PDA narrowest diameter

The narrowest diameter of the PDA measured by TTE and angiography for the study population was comparable; 2.53 ± 1.02 mm vs 2.53 ± 1.22 mm; p = 0.99 (Table 1). Bland–Altman plot analysis revealed no significant bias between TTE and angiography with a standard deviation of 0.9 and narrow 95% limits of agreement of 1.8 and −1.8 (Fig. 4a).

3.2. Aortic ampulla diameter

There was a statistically significant difference between the diameter of the aortic ampulla on TTE vs angiography; 10.2 ± 3.1 mm vs 9.6 ± 2.9 mm, p = 0.047 (Table 1). Bland–Altman plot analysis revealed a mean bias of 0.57 between TTE and angiography with a standard deviation of 3.2 and wide 95% limits of agreement of 7.0 and −5.8 (Fig. 4b).

3.3. PDA length

Echocardiography slightly overestimated the PDA length compared to angiography and the difference was statistically significant; 10.5 ± 3.1 mm vs 9.7 ± 2.9 mm; p = 0.01 (Table 1). Bland–Altman plot analysis revealed a bias of 0.85 between TTE and angiography with a standard deviation of 3.8 and wide 95% limits of agreement of 8.5 and −6.8 (Fig. 4c).

3.4. PDA type (shape)

The difference between the two imaging modalities in determining the PDA type was statistically

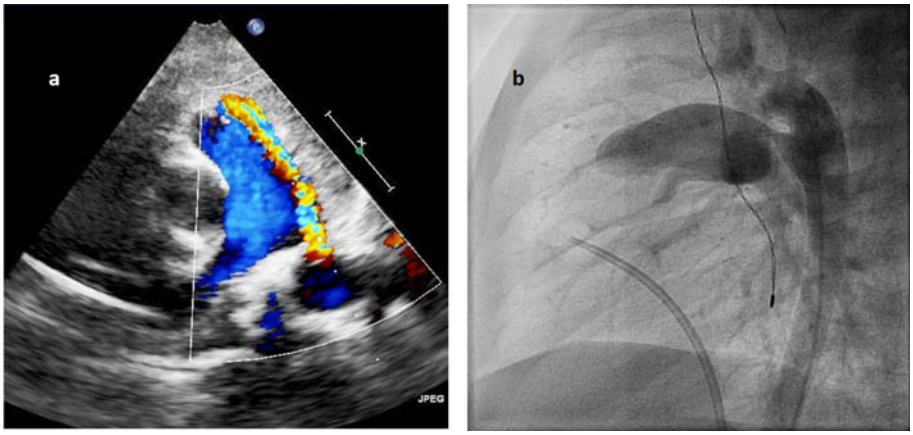

Fig. 3. Comparison of PDA type between Echocardiography and angiography showing in both a conal shape PDA of similar measurements. 3a) Echo: Smallest diameter (pulmonic end) = 3 mm. Largest diameter (aortic end) = 4.4 mm. Ductal length = 10 mm. 3b) Angiography: Smallest diameter (pulmonic end) = 2.6. Largest diameter (aortic end) = 3.8. Ductal length = 12 mm.

Table 1. Comparison between PDA measurements and types of PDA by echocardiography vs angiography.

PDA Dimensions (mm)	Echocardiography	Angiography	P value
Narrowest Diameter	2.53 ± 1.02	2.53 ± 1.22	0.99
Aortic Ampulla Diameter	10.2 ± 3.1	9.6 ± 2.9	0.04
PDA Length	10.5 ± 3.1	9.7 ± 2.9	0.01
PDA Type:			
Conal	90	107	
Conal small	17	5	
Convex	9	7	
Tiny	7	5	
Tubular	8	1	
AP Window	0	4	
Elongated	0	2	

PDA: Patent Ductus Arteriosus; AP window = aorto pulmonary window.

significant ($\chi^2 = 87.9$, $p < 0.01$), in spite of that, the shape of the PDA was correctly identified in the majority of cases [108 patients (82%)].

3.5. Device selection

The type and size of the device (either Amplatzer or coil) used based on angiography was correctly predicted by TTE in the majority of cases (n = 115) and the difference between the two modalities in device selection was not statistically significant ($\chi^2 = 1.23$, $p = 0.54$).

A subgroup analysis of patients less than one year of age (n = 40) was performed. In this subgroup there was no statistically significant difference in any of the measurements of echocardiography vs angiography respectively: PDA narrowest diameter 2.98 ± 0.93 vs 2.93 ± 1.19; p = 0.7, PDA ampulla 9.55 ± 2.23 vs 9.04 ± 2.92; p = 0.3, PDA length 10.42 ± 2.84 vs 10.04 ± 2.56; p = 0.4, PDA shape ($\chi2 = 8.9$, $p = 0.1$), device type ($\chi2 = 1.3$, $p = 0.53$)].

4. Discussion

Percutaneous occlusion of the PDA under echocardiography guidance avoiding arterial complications and administration of contrast agent is being explored by many investigators [5,6]. While positioning of the device and adequacy of PDA occlusion can be reliably monitored under echocardiographic guidance [8], one of the challenges is appropriate device selection without angiographic delineation of the PDA anatomy. Current experience of closing PDA under echocardiographic guidance suggests that this approach can be successful in most cases but the examiner's ability to select appropriate devices solely based on echocardiographic imaging has not been systematically investigated.

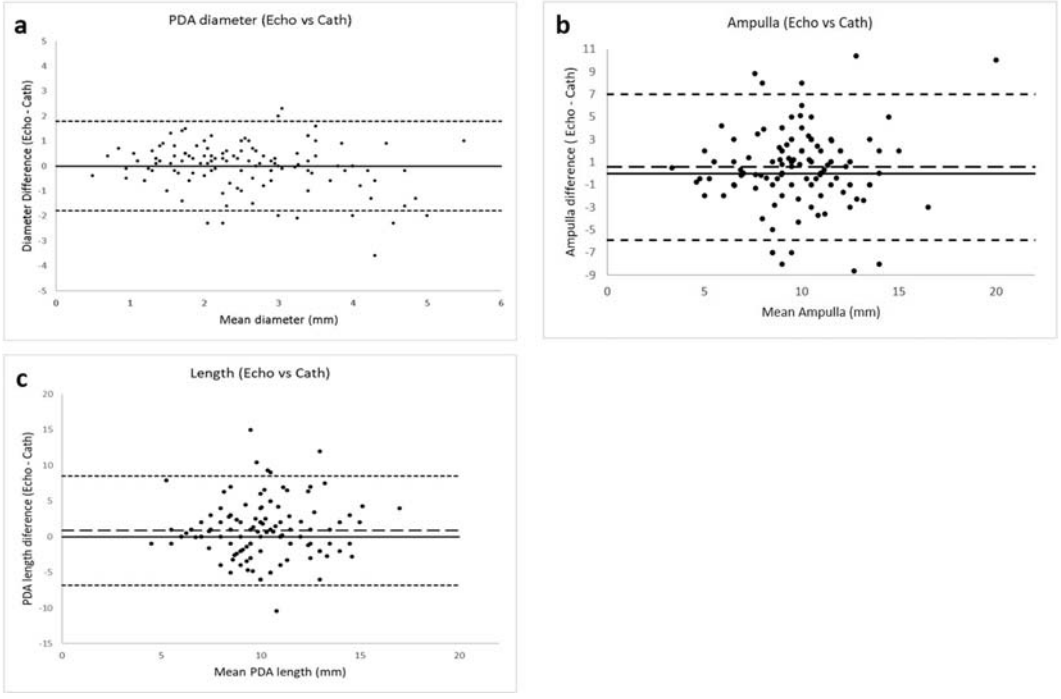

Fig. 4. Bland Altman Plot Analysis. a) Excellent agreement between echo and cath PDA narrowest diameter. The large-dash line represents the mean difference which coincides with zero indicating no significant bias. Small –dashed lines indicate the upper and lower 95% limits of agreement which is narrow. b) Modest agreement with wide scatter between echo and cath ampulla diameter. c) Weak agreement with wide scatter between echo and cath PDA length.

In this retrospective study of 131 patients, we found that routine echocardiography performed-despite its limitations-extremely well in determining the PDA's narrowest diameter and in predicting the appropriate occluding device type. On the other hand, echocardiographic measurements of the ampulla's diameter and PDA length were overestimated when compared to angiography. However, this difference was not clinically relevant. Furthermore, echocardiography was unable to accurately describe the PDA shape in some patients. In children under one year of age there was excellent correlation between Echo and angiographic findings in all the measurements. This is likely due to better acoustic windows in infants.

Despite these findings, the type and size of the device to successfully occlude the PDA could be correctly predicted by transthoracic echocardiographic imaging of the PDA in the parasternal long axis plane using the ductal view. This is an interesting and important observation. The most relevant aspect of the procedure is successful occlusion of the PDA without causing obstruction to flow in the aorta and pulmonary artery. In this regard, echocardiography seems to perform as well as angiography. In our series the majority (117/131 - 89%) of PDAs were either conal or convex shape-more than previously described by Kritchenko et al. (1989). Occlusion was achieved using either Amplatzer duct occluders (ADO I or ADO II) device or detachable coils for smaller PDAs. In our practice the ADO device selection on angiography is made based on the narrowest diameter, diameter of the aortic ampulla and length of the PDA. In long ductus (>7 mm), we incorporate the mid-PDA diameter in decision making for device selection.

The shapes of the conal and convex type PDA are slightly different but, in our experience, the ADO I is well suited for both shapes. In contrast, the geometry of tubular, AP window type, and tiny PDAs are less common (Table 1). Analysis of the data after excluding those cases did not change the results except that the diameter of the aortic ampulla measured by echocardiography were similar to angiographic measurements (10.3 ± 3.1 mm vs 9.9 ± 2.8 mm, $p = 0.1$ respectively). The results of the narrowest diameter, PDA length, shape, and device selection remained unchanged. This is likely because the number of tubular and AP window type PDAs were very small and tiny PDAs can be occluded easily with a detachable coil or small ADOI/ADO II device, depending upon the size of the aortic ampulla and on the preference of the operator.

We often use detachable coils for PDA with the narrowest diameter less than 1.5 mm. A coil with 2–3 times the narrowest diameter of the PDA and with enough loops to fill the ductal ampulla achieve successful occlusion in these cases. However, in our experience, TTE guidance alone could be very challenging in these cases as the operator is unable to visualize the whole coil cable. Therefore, in case the operator needed to use detachable coil echocardiography alone might not be the best option and we find limited fluoroscopy quite beneficial in this situation. Fluoroscopy might also be used to expedite some aspects of the TTE guided anterograde PDA occlusion (8).

Therefore, TTE appears to be a suitable imaging modality on its own to select an appropriate PDA occluding device for conal, convex, and likely tiny PDAs but this observation cannot be generalized for less common types of PDA, such as large tubular or AP window type PDA [3]. Rarely, PDAs demonstrate an expansile phenomenon, where the size of the PDA, including the narrowest diameter changes dramatically from small to large [13]. We have also come across a case where a PDA with a small narrowest diameter on initial angiography expanded to a huge PDA after catheter manipulation. In such cases, prior echocardiographic assessment and device selection would obviously not remain relevant. Fortunately, these are rare situations, but the operator and the family need to be aware of such a possibility, especially when the access to devices is limited.

5. Access for PDA closure

Since the inception of percutaneous device closure of the PDA, femoral arterial access to perform aortic angiography and delineate the PDA anatomy has been the first essential step and remains so in many catheterization laboratories. However, arterial access could be associated with significant complications, including arterial thrombosis and complete or partial occlusion of the femoral artery in approximately 0.8%–7% of children and as high as 19% in young infants weighing less than 4 Kg [14,15]. Rarely limb threatening ischemia is encountered, necessitating thrombolysis or surgical intervention [16].

Transvenous PDA occlusion under TTE guidance without arterial access has been shown to be feasible. It offers an obvious advantage over conventional approach by avoiding arterial access and associated arterial complication and has allowed bedside occlusion of PDA in fragile premature

newborns without transferring them to the catheterization laboratory [11]. Despite these advantages TTE guided transvenous approach without arterial access is still not widely practiced, as excellent angiographic imaging of the PDA can be sometimes challenging. The findings of our study lend further support for wider acceptance of this approach.

6. PDA closure in developing countries

Our findings have another important practical implication for a large patient population and pediatric cardiologists in underdeveloped countries. In these resource limited populations, the operator does not have unrestricted access to a variety of devices in all sizes. Feasibility of echocardiography to reliably narrow down and predict the type and size of the device is a welcoming tool to guide planning a procedure with successful outcome in advance.

Occasionally PDA cannot be accessed anterograde and in these cases, retrograde occlusion can also be performed solely under TTE guidance using ADO II, vascular plugs or detachable coils. ADO I is not suitable for retrograde occlusion of PDA.

6.1. Limitations

In addition to the usual limitations of the retrospective single center study and selection bias, the findings of this study are primarily applicable to young children with conal and convex shape PDA. These findings cannot be generalized to other less common types or unusually large PDAs (>7 mm). As expected, the conal type represents the majority of the patients studied. Hence the correlation between echo and angio finding was high. This might not be the case with the less common PDA types. Because of low numbers of the other PDA types, predictive value analysis was not performed.

6.2. Conclusion

In young children echocardiographic imaging of the PDA in the parasternal long axis plane using ductal view allows reliable assessment of the narrowest diameter of the PDA similar to angiography. However, this imaging technique is less accurate in measuring the aortic ampulla and the length of the PDA in children older than one year of age. Despite these limitations, appropriate selection of ADO devices or detachable coils can be made based on the shape and narrowest diameter of conal/convex shape PDAs. With advancement in technology and better ECHO resolution it is possible that in future straight forward PDA device occlusion in younger population can solely be done under ECHO guidance. At this stage, more prospective data is needed before adopting echo as a sole method to guide PDA device closure.

Author contribution

Conception and design of Study: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain. Acquisition of data; Data collection: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Masroor Sharfi, Fayzah El Khattab. Analysis and interpretation of data: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Fayzah El Khattab, Riad Abou Zahr. Research investigation and analysis; Research coordination and management: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Riad Abou Zahr. Drafting of manuscript: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Masroor Sharfi, Yahia El Mahdi, Fayzah El Khattab, Amjad Alkouatli, Riad Abou Zahr. Rev"sing and editing the manuscript critically for important intellectual contents: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Yahia El Mahdi, Fayzah El Khattab, Amjad Alkouatli, Riad Abou Zahr. DataprepazaGonand presentation: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Yahia El Mahdi, Riad Abou Zahr. Supervision of the research: Mohammed Omar Galal, Zaheer Ahmed, Arif Hussain, Amjad Alkouatli, Riad Abou Zahr.

Conflict of interest statement

No conflict of interests.

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