

Echocardiographic approach to transcatheter closure of atrial septal defects in children with a deficient or absent aortic rim: a retrospective analysis

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Received 17 March 2026. Revised 17 June 2026.

Accepted 23 June 2026.

How to cite: Kurako M.M., Abramyan M.A., Kulagina T.Yu., Pursanov M.G. Echocardiographic approach to transcatheter closure of atrial septal defects in children with a deficient or absent aortic rim: a retrospective analysis. *Patologiya krovoobrashcheniya i kardiokhirurgiya = Circulation Pathology and Cardiac Surgery*. 2026;30(3):49-56. (In Russ.)

<https://doi.org/10.21688/1681-3472-2026-3-49-56>

Funding

The study did not have sponsorship.

Conflict of interest

The authors declare no conflicts of interest.

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Abstract

Introduction: Transcatheter closure of secundum atrial septal defects (ASDs) is the standard of care. However, defects with a deficient or absent aortic rim remain technically challenging because of the risk of erosion of the aortic wall or atrial roof. Despite extensive international experience, techniques for the safe closure of such defects in children remain insufficiently studied in Russian clinical practice.

Objective: To develop and evaluate the effectiveness of a differentiated occluder-sizing algorithm based on comprehensive echocardiographic imaging to minimize the risks of transcatheter ASD closure in children with a deficient aortic rim.

Methods: A retrospective analysis was performed in 265 children with an isolated deficient or completely absent aortic rim. Transthoracic (TTE) and transesophageal echocardiography (TEE) were the principal imaging modalities used for monitoring at all stages of the procedure. A personalized approach to device sizing was applied: in patients with firm rims, device size was determined using echocardiography with color Doppler mapping; in patients with thin rims, the stop-flow technique was used. Particular attention was paid to the device-to-body-weight ratio (device diameter/body weight).

Results: The mean device-to-body-weight ratio in the study group was 0.88, which helped avoid excessive pressure on cardiac structures. Implementation of the differentiated algorithm, involving selection of an occluder 2 mm smaller to 2 mm larger than the measured size depending on the echocardiographic appearance of the rims, resulted in a high technical success rate. During the entire follow-up period (median, 38 months; interquartile range [IQR], 24–52 months; range, 6–84 months), there were no cases of aortic erosion or other life-threatening complications.

Conclusion: Transcatheter ASD closure in children with a deficient aortic rim is a safe procedure provided that the imaging protocol is strictly followed and the occluder is appropriately sized. The proposed algorithm and monitoring of the device-to-body-weight ratio minimize mechanical stress on the aortic root and provide excellent clinical outcomes.

Keywords: aortic and atrial wall erosion; atrial septal defect; deficient aortic rim; echocardiography; occluder; stop-flow technique; transcatheter intervention



Эхокардиографический подход при эндоваскулярном закрытии дефектов межпредсердной перегородки у детей с дефицитом или отсутствием аортального края: ретроспективный анализ

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Поступила в редакцию 17 марта 2026 г.

Исправлена 17 июня 2026 г. Принята к печати 23 июня 2026 г.

Цитировать: Курако М.М., Абрамян М.А., Кулагина Т.Ю., Пурсанов М.Г.

Эхокардиографический подход при эндоваскулярном закрытии дефектов межпредсердной перегородки у детей с дефицитом или отсутствием аортального края: ретроспективный анализ. *Патология кровообращения и кардиохирургия*. 2026;30(3):49-56.

<https://doi.org/10.21688/1681-3472-2026-3-49-56>

Финансирование

Исследование не имело спонсорской поддержки.

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Вклад авторов

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Аннотация

Актуальность. Эндоваскулярное закрытие вторичных дефектов межпредсердной перегородки (ДМПП) является стандартом лечения, однако случаи с дефицитом или отсутствием аортального края остаются технически сложными из-за риска развития эрозии стенки аорты или крыши предсердия. Несмотря на наличие обширной мировой статистики, в отечественной практике методики безопасного закрытия таких дефектов у детей изучены недостаточно.

Цель. Разработка и оценка эффективности дифференцированного алгоритма подбора окклюдера на основе комплексной эхокардиографической визуализации для минимизации рисков при транскатетерном закрытии ДМПП с дефицитом аортального края у детей.

Методы. Проведен ретроспективный анализ результатов лечения 265 детей с изолированным дефицитом или полным отсутствием аортального края. Ведущим инструментом контроля на всех этапах выступали трансторакальная (ТТЭХОКГ) и чреспищеводная эхокардиография (ЧПЭХОКГ). Применялся персонализированный подход к выбору размера устройства: при плотных краях размер определялся по данным эхокардиографии с цветным доплеровским картированием, при истонченных – техникой stop-flow. Особое внимание уделялось индексу соразмерности (диаметр устройства / масса тела пациента).

Результаты. Среднее значение индекса соразмерности в исследуемой группе составило 0,88, что позволило избежать чрезмерного давления на структуры сердца. Внедрение дифференцированного алгоритма (выбор размера окклюдера от –2 до +2 мм в зависимости от эхо-картины краев) обеспечило высокую техническую успешность вмешательств. За весь период наблюдения (Me = 38 мес., [IQR]: 24–52 мес.; диапазон: от 6 до 84 мес.) не было зафиксировано ни одного случая эрозии аорты или других жизнеугрожающих осложнений.

Заключение. Транскатетерное закрытие ДМПП при дефиците аортального края у детей является безопасным методом при условии строгого соблюдения протокола визуализации и корректного подбора размера окклюдера. Использование предложенного алгоритма и контроль индекса соразмерности минимизируют механическое воздействие на корень аорты, обеспечивая отличные клинические результаты.

Ключевые слова: дефект межпредсердной перегородки; дефицит аортального края; окклюдер; техника stop-flow; эндоваскулярная хирургия; эрозия стенки предсердия и аорты; эхокардиография



Introduction

In contemporary cardiac surgery, transcatheter closure of secundum atrial septal defects (ASDs) using occluder devices has become the standard treatment, replacing open surgical patch closure [1; 2]. The key prerequisite for reliable and safe transcatheter ASD closure is the presence of adequately developed rims of sufficient height. In particular, a deficient or absent aortic (anterior) rim was previously considered a major technical challenge and even a contraindication to transcatheter intervention for secundum ASDs [3]. A deficient rim is currently defined as a rim height of less than 5 mm, whereas an absent rim is defined as a height of less than 1 mm [3]. This anatomical feature is associated with the risk of one of the most serious intraoperative and postoperative complications – erosion of the aortic wall or atrial roof [4; 5].

According to the literature, the overall incidence of erosion is approximately 0.10–0.27% [4–6]. Importantly, erosion may be delayed, becoming clinically apparent months or even years after successful device implantation [6; 7]. Various studies have reported that up to 89% of all cases of this life-threatening complication, which may be accompanied by massive bleeding, occur in patients with a deficient aortic rim [5; 6; 8]. Under these conditions, an implanted occluder may closely contact or encircle the aortic root, producing persistent mechanical trauma. This is considered the principal pathophysiological mechanism underlying both early and late erosions [5–8].

The second most important serious complication is device embolization (migration), reported in up to 0.62% of cases. It occurs more frequently during the early postoperative period when an undersized occluder is used and/or when there is concomitant deficiency of other rims [9; 10].

Analysis of published studies indicates that the key modifiable risk factor for vascular-wall erosion is not only the anatomy of the defect but also the technical accuracy of occluder sizing. In approximately half of the reported cases of erosion after use of contemporary occluders in children, the complication was associated with device

oversizing by 2 mm or more relative to the measured defect size [6; 7]. This finding confirms that prevention of complications requires an accurate and differentiated approach to determining the optimal occluder size.

Despite the accumulated international experience, Russian-language literature has paid insufficient attention to the methods and problems of ASD closure in children with a deficient aortic rim, including long-term risks and prevention of delayed complications. In the present study, we retrospectively analyzed transcatheter closure of ASDs with a deficient or absent aortic rim, developed a strategy for safe and successful closure, and evaluated the early and long-term outcomes of the intervention.

Methods

Between October 2018 and December 2025, 750 children underwent transcatheter closure of secundum ASDs in the Department of Emergency Cardiac Surgery and Interventional Cardiology of Morozov Children's City Clinical Hospital. Of these, 265 had defects with a deficient or absent aortic rim. The mean age was 8.5 years (95% confidence interval [CI], 7.8–10.6 years). Girls predominated: 155 (58.5%; 95% CI, 47.1–69.3%), while there were 110 boys (41.5%; 95% CI, 30.7–52.9%). Patient anthropometric characteristics are presented in Table 1.

All patients had evidence of a hemodynamically significant left-to-right shunt. The mean pulmonary-to-systemic blood-flow ratio was 1.63:1 (95% CI, 1.54–1.68), with right-sided cardiac volume overload.

To assess the anatomy of the interatrial septum (IAS) and select an occluder, all patients initially underwent detailed transthoracic echocardiography (TTE) using Philips EPIQ 7 (Philips, the Netherlands/USA) and Vivid S70 (GE Healthcare, USA) systems equipped with phased-array transducers operating at 2.5–8.0 MHz. In addition to determining defect size, the IAS rims, their height and stability, and the total length of the IAS were assessed. The latter was measured by TTE in subcostal, suprasternal, and apical views and/or by transesophageal echocardiography (TEE) in three standard imaging planes:

Table 1. Anthropometric characteristics of patients with ASD and a deficient or absent aortic rim

Variable	M ± SD	95% CI	min	max
Age, years	8.5 ± 3.9	8.03–8.97	3.0	17.0
Weight, kg	32.8 ± 17.5	30.69–34.91	14.5	90.0
Height, cm	138.4 ± 22.1	135.74–141.06	88.0	190.0
BSA, m ²	1.05 ± 0.35	1.008–1.092	0.55	2.10

Note. BSA, body surface area; M, arithmetic mean; SD, standard deviation; 95% CI, 95% confidence interval; min and max, minimum and maximum values in the study sample, respectively.

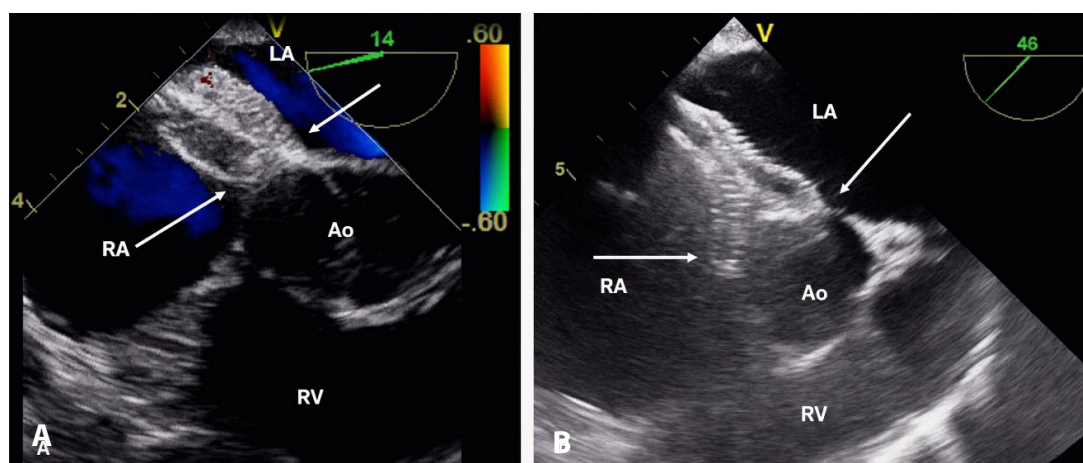


Fig. 1. Transesophageal echocardiographic images in the short-axis view of the aorta. (A) The edges of the occluder discs contact the aortic wall, as indicated by the arrows. (B) The occluder discs encircle the aortic root, as indicated by the arrows

Note. Ao, aorta; LA, left atrium; RV, right ventricle; RA, right atrium.

0°, 45°, and 90°. All defects were classified as large (ASD diameter/body surface area [BSA] > 15 mm/m²), moderate (5–15 mm/m²), or small (< 5 mm/m²) [11; 12].

Preoperative TEE for assessment of IAS anatomy was not required in all patients because TTE images were optimal owing to the good acoustic windows in children. However, in patients with large defects and thin remaining rims, intraoperative TEE was used throughout the procedure. Given the age and body weight of the pediatric patients, three-dimensional TEE could not be used in this patient group.

The ratio of occluder size to the child's body weight (device diameter/body weight) was assessed in all patients. For safe implantation and to reduce the risk of postoperative complications, this ratio should not exceed 1. Some authors believe that transcatheter closure should not be performed in small children weighing less than 20 kg if this ratio exceeds 1.5 [13].

Transcatheter occluder implantation was performed using a standard technique. In patients with large ASDs and thin rims, deployment of the left atrial disc from the right or left pulmonary vein and a balloon-assisted technique were used.

The study protocol was approved by the Local Independent Ethics Committee of Morozov Children's City Clinical Hospital (Protocol No. 12/2023 dated March 15, 2023).

In patients with ASDs and relatively firm rims, occluder size was selected on the basis of TTE and/or TEE findings, taking into account the maximum diameter of the

interatrial communication measured by color Doppler mapping in one of the three views.

In patients with large anterior ASDs and thin rims, the ASD size was determined and the occluder selected using a sizing balloon with the stop-flow technique. The balloon was advanced through a venous introducer sheath over a guidewire and positioned with its midportion within the defect under the guidance of intraoperative TEE (or TTE when an adequate acoustic window was available) and fluoroscopy. The balloon was then slowly inflated with diluted contrast medium while cessation of the transseptal shunt was monitored by color Doppler mapping. We did not use the appearance of a "waist" on the balloon as a reference, as in standard angiography, because overdistension of the deficient rims in children may result in a falsely increased diameter and, consequently, selection of an excessively large occluder. In this situation, the device size was set equal to the balloon diameter measured by echocardiography.

When a child had a small or moderate defect with thin rims, device size was selected according to the diameter determined using the sizing balloon.

Occluder selection also depended on the presence or absence of the subaortic rim. When the subaortic rim was deficient, an occluder smaller than the calculated size was selected; in this situation, the edges of the occluder discs should only contact the aortic root (Fig. 1, A). When the subaortic rim was absent, an occluder larger than the calculated size was selected; in this situation, the occluder discs encircle the aortic root (Fig. 1, B) but do not compress it.

Table 2. Echocardiographic characteristics of ASDs with a deficient or absent aortic rim

Variable	M ± SD	95% CI	Min	Max
Occluder diameter/body weight	0.88 ± 0.25	0.85–0.91	0.4	1.34
ASD/BSA, mm/m ²	11.2 ± 6.0	10.5–11.9	6.5	29.5
ASD/body weight, mm/kg	0.75 ± 0.24	0.72–0.78	0.35	1.33
Total shunt size, mm	11.9 ± 4.7	11.3–12.5	2.5	22.0

Note. ASD, atrial septal defect; BSA, body surface area; M, arithmetic mean; SD, standard deviation; 95% CI, 95% confidence interval; min and max, minimum and maximum values in the study sample, respectively; ASD/BSA, defect size indexed to body surface area, mm/m²; ASD/body weight, ratio of defect size to patient body weight, mm/kg.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). The normality of quantitative variables was assessed using the Shapiro–Wilk test. The distributions of most anthropometric and echocardiographic variables (age, weight, height, BSA, defect size, and the ASD/BSA and ASD/body-weight indices) did not significantly deviate from normality. Therefore, these variables were described using the arithmetic mean (M) and standard deviation (SD), and 95% CIs for the means were calculated as $M \pm 1.96 \times (SD/\sqrt{n})$.

For variables with distributions that differed significantly from normality, particularly follow-up duration, a nonparametric approach was used. Data were presented as the median and interquartile range (IQR), with the overall range (min–max) also reported. To assess factors potentially influencing the development of a minor residual shunt, multivariable logistic regression analysis with stepwise variable entry was planned; however, because of the small number of events and the absence of major complications, the regression model was not applied. Complication-free survival analysis was not performed because no adverse events occurred in the study cohort. The threshold for statistical significance was set at $p = 0.05$. All statistical tests were two-sided. Results were considered statistically significant at $p < 0.05$.

Results

Among the 265 children with anterior ASDs, complete absence of the aortic rim was diagnosed in 57 patients, while 208 had a deficient rim. The mean defect size was 11.9 mm (range, 10.9–13.0 mm). Small defects were present in 115 (43.4%) children, moderate-sized interatrial communications in 128 (48.3%), and large defects in 22 (8.3%) patients. Echocardiographic characteristics of the ASDs are presented in Table 2.

The procedural success rate was 99.6%. In only one case, involving a child with a large defect (ASD/BSA = 22 mm/m²), a deficient subaortic rim, and thin remaining rims, the decision was made not to implant an occluder because no waist was observed on the sizing balloon during angiography or with the stop-flow technique. The child subsequently underwent elective surgical repair under cardiopulmonary bypass.

In two patients with a deficient and thin aortic rim, the occluders were exchanged intraoperatively. After initial deployment, significant shunting was detected along the upper edge of the occluder discs; the devices were replaced with larger ones, and no residual shunt was detected on control echocardiography. In another child with a deficient aortic rim, echocardiography during implantation showed that the left atrial disc of the device was pressing against the aortic wall (Fig. 2). After the device was replaced with a smaller one, it encircled the aortic root in a V-shaped configuration; no signs of aortic-wall compression or residual shunting were detected.

Immediately after the procedure, complete ASD closure was achieved in 226 (85.6%) patients, defined as complete sealing of the defect with no interatrial shunt detected by echocardiography. A minor residual shunt was detected immediately after the procedure in 38 (14.4%) patients. At hospital discharge, a minor residual shunt through the device persisted in 25 patients. In 20 children, the shunt was located between the occluder discs, whereas in only five patients was it located at the margins of the occluder.

Long-term outcomes were available for 227 (85.9%) patients, with follow-up ranging from 6 to 84 months. The median follow-up duration was 38 months (IQR, 24–52 months; range, 6–84 months). Neither early nor late complications – including device embolization, cardiac erosion, thromboembolism, infective endocarditis, or atrioventricular block – occurred in our study. Patients underwent clinical follow-up, electrocardiography, and TTE at 1, 3, 6, and 12 months and annually thereafter.

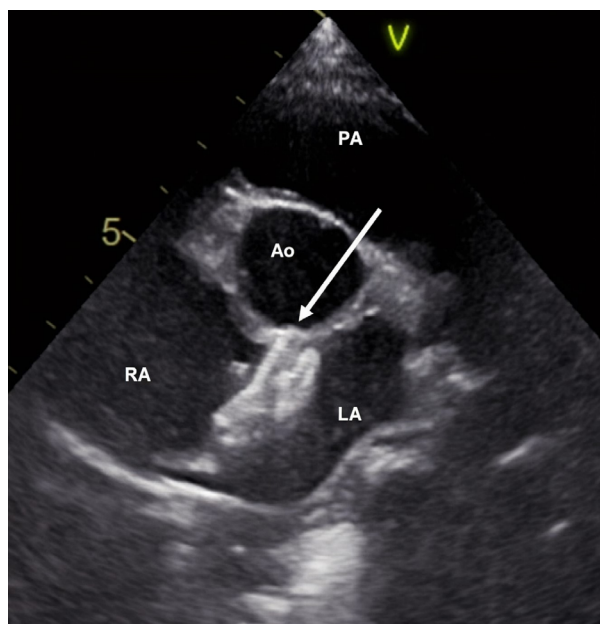


Fig. 2. Transthoracic echocardiography, short-axis view of the aorta. The arrow indicates indentation of the left atrial disc of the occluder into the aortic wall

Note. Ao, aorta; PA, pulmonary artery; LA, left atrium; RA, right atrium.

Discussion

Transcatheter closure of secundum ASDs has become the standard treatment; however, defects with a deficient or absent aortic rim remain controversial because of the risk of a rare but life-threatening complication – erosion of the aortic wall or atrial roof [8; 9]. The first reports of this problem date back to 2004 and were associated with use of the Amplatzer Septal Occluder (ASO; Abbott, USA). The reported incidence was approximately 0.1%, and the complication could present as late as 5 years after the procedure [4; 5; 14–16]. The pathogenesis of erosion is directly related to mechanical interaction between the edge of the occluder disc and the vulnerable area of the left atrial roof and aortic root, particularly in the absence of adequate tissue support [9; 10; 17; 18].

Subsequent analyses of large series showed that erosion was the second most frequent serious complication (22.9%), after device migration. Nevertheless, the overall mortality associated with erosion (0.05%) remained lower than that associated with surgical closure of the defect (0.13%) [19, 20]. At the same time, contemporary occluders, such as devices manufactured by Lepu Medical (China) and the Figulla device (Occlutech, Germany/Switzerland), have demonstrated high success rates of

up to 99.3% and low erosion rates when the implantation technique is properly performed [11; 19; 21; 22]. Analysis of published cases of erosion after implantation of Occlutech devices in children (eight cases) suggests that the key risk factors include not only a deficient aortic rim, which was present in three of eight cases, but also a technical error involving occluder oversizing by 2 mm or more relative to TEE or balloon measurements [7; 23].

This finding emphasizes the paramount importance of accurate device sizing, particularly in children, because of ongoing cardiac growth. A generally accepted reference is the ratio of occluder size to patient body weight, with an optimal value close to 1.0. Some investigators consider a device-diameter-to-body-weight ratio > 1.5 to be an absolute contraindication to transcatheter intervention in young children. Exceeding this threshold is associated with a high probability of aortic erosion and impaired function of intracardiac structures because of limited space within the atria [15; 24]. In our study of 265 children with an isolated deficient or completely absent aortic rim, no cases of erosion occurred. We believe that strict adherence to the device-diameter-to-body-weight ratio, which was 0.88 in our cohort, was the decisive safety factor, providing an adequate safety margin even in the presence of unfavorable rim anatomy.

Based on the literature and our own experience, we developed a differentiated algorithm in which the measurement strategy and occluder size depend on both the size of the aortic rim and the condition of all defect rims. This approach may mitigate the risks described in the literature [5–9].

1. For an ASD with a deficient aortic rim but preserved, firm remaining rims, occluder size is determined according to the maximum defect diameter measured by TTE or intraoperative TEE with color Doppler mapping. To ensure secure fixation by the firm rims, the device is selected to be equal to the measured diameter or 1–2 mm larger.
2. For small and moderate ASDs with an absent or deficient aortic rim and thin remaining rims, defect size is determined using a sizing balloon.
3. For large ASDs with an absent or deficient aortic rim and thin remaining rims, the stop-flow technique with balloon sizing is used. Unlike the standard angiographic reference of the balloon “waist,” the sizing balloon is inflated under echocardiographic guidance until the interatrial shunt completely ceases. This makes it possible to

determine the hemodynamically significant rather than the anatomical diameter; the former is then used as the occluder size. This approach prevents selection of an excessively large device due to overstretching of deficient defect rims.

After the baseline size has been obtained using the sizing balloon or stop-flow technique, a key adjustment is made to minimize mechanical contact with the aorta. When the aortic rim is deficient, preference is given to an occluder 1–2 mm smaller than the baseline size to reduce the area and force of contact between the left atrial disc and the risk zone and thereby avoid excessive contact. When the aortic rim is completely absent, an occluder 1–2 mm larger than the baseline size is implanted. This allows the broad device disc to safely encircle the aortic root, distributes pressure over a larger area, and prevents focal traumatic contact between the disc edge and the aortic wall [4; 25].

Study limitations

The retrospective design and absence of a control group – patients undergoing open surgical repair or closure with devices manufactured by other companies – preclude a direct comparative assessment of the effectiveness of the described algorithm versus alternative approaches. Nevertheless, the findings provide a basis for further prospective studies. It is also important to note

that the key defect-measurement method, the stop-flow technique, relies to a considerable extent on the practical experience of the echocardiographer, because cessation of shunting is identified by color Doppler mapping. This places specific demands on staff expertise and may affect reproducibility when the technique is implemented in centers with less experience in such interventions. These issues should be considered when planning multicenter studies.

Conclusion

In this study, transcatheter closure of ASDs with a deficient or absent aortic rim in children was a safe and effective method of correction, with excellent long-term outcomes.

The safety and effectiveness of transcatheter correction of this congenital heart defect in children may be enhanced by implementing a personalized, comprehensive protocol for selecting the size and type of occluder.

The proposed algorithm, based on sequential and detailed echocardiographic imaging, is the key to successful transcatheter correction of ASDs without an adequate aortic rim in children. It makes it possible to determine the closure technique and procedural strategy in advance, as well as the size of the device to be implanted.

References

1. Rigatelli G., Gianese F., Zuin M. Secundum Atrial Septal Defects Transcatheter Closure: An Updated Reappraisal. *Cardiovasc Revasc Med.* 2022;44:92-97. PMID: 35680528. <https://doi.org/10.1016/j.carrev.2022.06.002>
2. Soynov I.A., Kim A.I., Movsesyan R.R., Teplov P.V., Miller A.Yu., Kulyabin Yu.Yu., Avramenko A.A., Gorbatiykh K.V., Gorbatiykh A.V., Nalimov K.A., Abramyan M.A., Boriskov M.V., Kovalev S.A., Svobodov A.A., Arkhipov A.N., Krivoshechekov E.V., Amansakhatova E.N., Tarasyuk E.S. Surgical Management of congenital heart diseases in the Russian Federation: national registry data for 2024. *Patologiya krovoobrashcheniya i kardiokirurgiya = Circulation Pathology and Cardiac Surgery.* 2026;30(1):5-25. (In Russ.) <https://doi.org/10.21688/1681-3472-2026-1-5-25>
3. Silvestry F.E., Cohen M.S., Armsby L.B., Burkule N.J., Fleishman C.E., Hijazi Z.M., Lang R.M., Rome J.J., Wang Y.; American Society of Echocardiography; Society for Cardiac Angiography and Interventions. Guidelines for the Echocardiographic Assessment of Atrial Septal Defect and Patent Foramen Ovale: From the American Society of Echocardiography and Society for Cardiac Angiography and Interventions. *J Am Soc Echocardiogr.* 2015;28(8):910-58. PMID: 26239900. <https://doi.org/10.1016/j.echo.2015.05.015>
4. Amin Z., Hijazi Z.M., Bass J.L., Cheatham J.P., Hellenbrand W.E., Kleinman C.S. Erosion of Amplatzer septal occluder device after closure of secundum atrial septal defects: review of registry of complications and recommendations to minimize future risk. *Catheter Cardiovasc Interv.* 2004;63(4):496-502. PMID: 15558755. <https://doi.org/10.1002/ccd.20211>
5. Crawford G.B., Brindis R.G., Krucoff M.W., Mansalis B.P., Carroll J.D. Percutaneous atrial septal occluder devices and cardiac erosion: a review of the literature. *Catheter Cardiovasc Interv.* 2012;80(2):157-67. PMID: 22552868. <https://doi.org/10.1002/ccd.24347>
6. Jalal Z., Hascoet S., Baruteau A.E., Iriart X., Kreitmman B., Boudjemline Y., Thambo J.B. Long-term Complications After Transcatheter Atrial Septal Defect Closure: A Review of the Medical Literature. *Can J Cardiol.* 2016;32(11):1315.e11-1315.e18. PMID: 27179546. <https://doi.org/10.1016/j.cjca.2016.02.068>
7. Auriau J., Bouvaist H., Aaberge L., Abe T., Dähnert I., Panzer J., Santoro G., Khalil M., Hijazi Z.M., Fraisse A. Cardiac Erosions After Transcatheter Atrial Septal Defect Closure With the Occlutech Figulla Flex Device. *JACC Cardiovasc Interv.* 2019;12(14):1397-1399. PMID: 31320034. <https://doi.org/10.1016/j.jcin.2019.03.005>
8. Diab K., Kenny D., Hijazi Z.M. Erosions, erosions, and erosions! Device closure of atrial septal defects: how safe is safe? *Catheter Cardiovasc Interv.* 2012;80(2):168-74. PMID: 22718680. <https://doi.org/10.1002/ccd.24517>

9. Zhang Z.Q., Ding J.W. Perforation of the atrial wall and aortic sinus after closure of an atrial septal defect with an Atriasept occluder: a case report. *J Cardiothorac Surg.* 2021;16(1):53. PMID: 33766059; PMCID: PMC7993524. <https://doi.org/10.1186/s13019-021-01441-x>
10. Kitano M., Yazaki S., Sugiyama H., Ohtsuki S.I., Tomita H. Risk factors and predictors of cardiac erosion discovered from 12 Japanese patients who developed erosion after atrial septal defect closure using Amplatzer septal occluder. *Pediatr Cardiol.* 2020;41(2):297-308. PMID: 31732763. <https://doi.org/10.1007/s00246-019-02256-3>
11. Nakayama R., Takaya Y., Akagi T., Watanabe N., Miki T., Nakagawa K., Toh N., Ito H. Efficacy and safety of atrial septal defect closure using Occlutech Figulla Flex II compared with Amplatzer Septal Occluder. *Heart Vessels.* 2021;36(5):704-709. PMID: 33386412. <https://doi.org/10.1007/s00380-020-01739-1>
12. Baruteau A.E., Petit J., Lambert V., Gouton M., Piot D., Brenot P., Angel C.Y., Houyel L., Le Bret E., Roussin R., Ly M., Capderou A., Belli E. Transcatheter closure of large atrial septal defects: feasibility and safety in a large adult and pediatric population. *Circ Cardiovasc Interv.* 2014;7(6):837-43. PMID: 25423959. <https://doi.org/10.1161/CIRCINTERVENTIONS.113.001254>
13. Tanghöj G., Odermarsky M., Naumburg E., Liuba P. Correction to: Early Complications After Percutaneous Closure of Atrial Septal Defect in Infants with Procedural Weight Less than 15 kg. *Pediatr Cardiol.* 2021;42(2):468. PMID: 33575831; PMCID: PMC8025282. <https://doi.org/10.1007/s00246-021-02550-z>
14. Turner D.R., Owada C.Y., Sang C.J. Jr, Khan M., Lim D.S. Closure of Secundum Atrial Septal Defects With the AMPLATZER Septal Occluder: a Prospective, Multicenter, Post-Approval Study. *Circ Cardiovasc Interv.* 2017;10(8):e004212. PMID: 28801537; PMCID: PMC5559192. <https://doi.org/10.1161/CIRCINTERVENTIONS.116.004212>
15. Kenny D., Eicken A., Dähnert I., Boudjemline Y., Sievert H., Schneider M.B., Gori T., Hijazi Z.M.; Investigators. A randomized, controlled, multi-center trial of the efficacy and safety of the Occlutech Figulla Flex-II Occluder compared to the Amplatzer Septal Occluder for transcatheter closure of secundum atrial septal defects. *Catheter Cardiovasc Interv.* 2019;93(2):316-321. PMID: 30719850. <https://doi.org/10.1002/ccd.27899>
16. Onakatomi Y., Asou T., Takeda Y., Ueda H., Goda M., Masuda M. Aortic erosion occurring in over 5 years after Amplatzer septal Occluder implantation for secundum atrial septal defect: a case report. *J Cardiothorac Surg.* 2019;14(1):159. PMID: 31492164; PMCID: PMC6728993. <https://doi.org/10.1186/s13019-019-0982-z>
17. Dardas P.S., Ninios V.N., Mezilis N.E., Tsikaderis D.D., Thanopoulos V.D. Percutaneous closure of atrial septal defects: immediate and mid-term results. *Hellenic J Cardiol.* 2010;51(2):104-12. PMID: 20378511.
18. El-Said H.G., Moore J.W. Erosion by the Amplatzer septal occluder: experienced operator opinions at odds with manufacturer recommendations? *Catheter Cardiovasc Interv.* 2009;73(7):925-30. PMID: 19455668. <https://doi.org/10.1002/ccd.21931>
19. Roymanee S., Promphan W., Tonklang N., Wongwaitawee-wong K. Comparison of the Occlutech * Figulla * septal occluder and Amplatzer * septal occluder for atrial septal defect device closure. *Pediatric Cardiology.* 2015;36(5):935-41. PMID: 25633819. <https://doi.org/10.1007/s00246-015-1103-y>
20. Takaya Y., Akagi T., Nakagawa K., Nakayama R., Miki T., Toh N., Ito H. Feasibility of transcatheter closure for absent aortic rim in patients with atrial septal defect. *Catheter Cardiovasc Interv.* 2021;97(5):859-864. PMID: 33458916. <https://doi.org/10.1002/ccd.29457>
21. Rao P.S., Harris A.D. Recent advances in managing septal defects: atrial septal defects. *F1000Res.* 2017;6:2042. PMID: 29250321; PMCID: PMC5701442. <https://doi.org/10.12688/f1000research.11844.1>
22. Shrivastava S., Shrivastava S., Allu S.V.V., Schmidt P. Transcatheter Closure of Atrial Septal Defect: A Review of Currently Used Devices. *Cureus.* 2023;15(6):e40132. PMID: 37425612; PMCID: PMC10329454. <https://doi.org/10.7759/cureus.40132>
23. Bocalandro F., Baptista E., Muench A., Carter C., Smalling R.W. Comparison of intracardiac echocardiography versus transesophageal echocardiography guidance for percutaneous transcatheter closure of atrial septal defect. *Am J Cardiol.* 2004;93(4):437-40. PMID: 14969617. <https://doi.org/10.1016/j.amjcard.2003.10.037>
24. Ohno N., Chaturvedi R., Lee K.J., Benson L. Characteristics of secundum atrial septal defects not percutaneously closed. *Catheter Cardiovasc Interv.* 2015;85(2):234-9. PMID: 25315692. <https://doi.org/10.1002/ccd.25700>
25. Jung S.Y., Choi J.Y. Transcatheter closure of atrial septal defect: principles and available devices. *J Thorac Dis.* 2018;10(Suppl 24):S2909-S2922. PMID: 30305951; PMCID: PMC6174149. <https://doi.org/10.21037/jtd.2018.02.19>