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Delayed Closure of Secundum Atrial Septal Defect Leading to Eisenmenger Syndrome: A Case Report of Missed Intervention and Optimized Medical Therapy

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Abstract: ***Atrial septal defect (ASD) is frequently underdiagnosed until adulthood due to its often-silent early course. If left untreated, it may lead to serious complications such as Eisenmenger syndrome. This case report details the clinical course of a 45-year-old woman with a longstanding secundum ASD complicated by severe pulmonary hypertension and right-to-left shunting, following delays in planned percutaneous closure due to the COVID-19 pandemic. The patient presented with acute decompensated right heart failure and bronchopneumonia. Echocardiography and right heart catheterization confirmed irreversible pulmonary vascular disease. Management included pulmonary vasodilators, diuretics, infection control, and supportive therapy, while surgical closure was contraindicated. This case highlights the need for early diagnosis and continuous follow-up to prevent irreversible complications in congenital heart disease. However, delayed diagnosis and management continue to pose a significant clinical challenge, particularly in resource-limited healthcare settings.***

Keywords: Atrial Septal Defect, Eisenmenger Syndrome, Pulmonary Hypertension, Right Heart Failure, Case Report

1. Introduction

Atrial septal defect (ASD) is a common congenital heart defect (CHD) with a worldwide incidence of 1.64 per 1,000 live births whereas Ostium secundum ASD is the most prevalent type accounting for 70% to 80% of all cases.[1]

The absence of major clinical symptoms and physical findings can lead to delayed diagnosis; as such, ASDs are often diagnosed in adulthood. Left-to-right shunting may result in right heart enlargement and RV (right ventricle) dysfunction and, in a minority of patients, PAH (Pulmonary Arterial Hypertension/PH). Some patients may also have right-to-left shunting or paradoxical embolism, and others may develop arrhythmias.[2]

Up to 90% of adults with untreated atrial septal defect will be symptomatic by 4th decade, and 30-49% will develop heart failure. 8–10% of these patients have pulmonary arterial hypertension with a female predominance regardless of age. Early natural history studies of unoperated large ASDs have indicated a risk of severe pulmonary hypertension with significant morbidity and mortality.[3] PH is a clinical disorder, incited by an extensive heterogeneous number of pathophysiological triggers, resulting in a rise in pulmonary arterial pressures, PVR, subsequent right heart failure and premature death. The haemodynamic definition of PH is a mean pulmonary arterial pressure (mPAP) of ≥25 mmHg at rest by means of right heart catheterization. More specifically, the definition of PAH, which describes a small proportion of patients displaying hemodynamic evidence of pre-capillary PH, whom, along with a mPAP ≥25 mmHg have the additional requisite of a pulmonary capillary wedge pressure (PCWP) of ≤15 mmHg, and a PVR of >3 Wood units. [4]

The incidence of PAH related to CHD (PAH-CHD) varies geographically, but a consensus of registries globally estimates that up to 10% of adults with CHD develop PAH. The pathophysiology in CHD, results from progressive vascular remodeling by a range of mechanisms depending on the underlying lesion. In PAH-CHD, often this is due to a defect with a left-to-right shunt large enough to allow sufficiently increased pulmonary blood flow to trigger a pathological mechanism whereby there is increased shear stress, endothelial dysfunction, smooth muscle hypertrophy, proliferation and progressive distortion of the pulmonary vasculature, thus contributing to the development of as the disease progresses, the pulmonary vascular resistance (PVR) rises. If right heart catheterization confirms this by meeting PAH criteria, the disease is often established and irreversible. [4]

The extreme of this is when a significant left-to-right shunt continues to elevate the PVR to reach systemic levels; the shunt then reverses to a right-to-left or bi-directional status, thus leading to clinical cyanosis and the development of the Eisenmenger syndrome (ES). At present, the prevalence of ES ranges from 25% to 50% within the PAH-CHD cohort. [4]

Generally, both ESC and AHA guidelines favor ASD closure in patients with no significant shunts and pulmonary hypertension present or with PH that can be treated effectively. However, the ESC guidelines are more restrictive for patients with significant PH who do not respond to treatment. .[5] This case report aims to illustrate the clinical consequences of delayed management in secundum atrial septal defect, emphasizing the progression to Eisenmenger syndrome and the challenges faced in resource-constrained healthcare settings. Highlighting this case emphasizes the importance of timely intervention in congenital heart disease and provides valuable insight into the management of Eisenmenger syndrome when advanced pulmonary vascular disease precludes surgical closure.

2. Case Study

A 45-year-old woman presented to the emergency department with complaints of progressive shortness of breath since 10 days ago, worsening with minimal exertion since 1 day before admission. Her symptoms were accompanied by central cyanosis, evidenced by pale bluish lips and bluish discoloration of the fingertips**.** The patient also presented with a cough producing pink, frothy sputum, suggestive of pulmonary edema or alveolar hemorrhage. There is no history of syncope, chest pain, or fever. The patient was first diagnosed with a secundum ASD with bidirectional shunt in 2016. In 2019, she was evaluated and deemed a candidate for percutaneous closure due to evidence of right heart dilation. However, the procedure was deferred due to pandemic. Patient had been lost to follow-up until the current. Prior to presenting to the emergency department, this patient had been taking sildenafil 20 mg and furosemide 40 mg irregularly, without regular follow-up or evaluation by a cardiologist since the onset of the COVID-19 pandemic.

On physical examination, BP is 80/45mm, heart rate is at 101 beats per minute regular, respiratory rate 32 times per minute, temperature is 36^0C. Oxygen saturation was 76% on room air. On general examination, the patient appeared to be pale with cyanotic lips and finger. Jugular venous distension was noted. Auscultation revealed a loud P2 component of the second heart sound and a systolic murmur at the left upper sternal border. Peripheral edema was present.

Chest X-ray showing patchy alveolar infiltrates, more prominent in the right apical region compared to the left. Bilateral air bronchograms are evident, consistent with pulmonary congestion and interstitial edema, suggestive of acute pulmonary edema. The asymmetric distribution of infiltrates, particularly in the right apex, raises the possibility of superimposed bronchopneumonia.

A 12-lead electrocardiogram (ECG) revealed sinus rhythm with a heart rate of 110 beats per minute. There was a right axis deviation, peaked P waves in leads II, III, aVF, and V2–V6 suggestive of right atrial enlargement. A dominant R wave was observed in lead V1, and the QRS complex was slightly prolonged at 108 ms. There were horizontal ST segment depressions noted in leads II, III, aVF, and V1–V4. The QT interval was within normal limits. These findings are consistent with right ventricular hypertrophy (RVH) and possible right atrial enlargement, often seen in patients with chronic volume or pressure overload of the right heart, such as in atrial septal defect (ASD) with pulmonary hypertension.

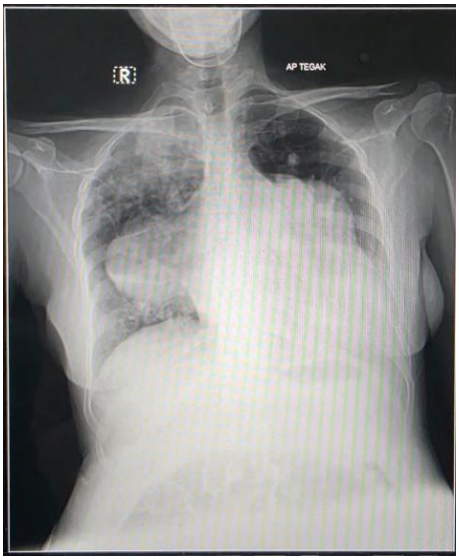

Figure 1: Chest X-ray showing cardiomegaly with sign of pulmonary hypertension and bronchopneumonia

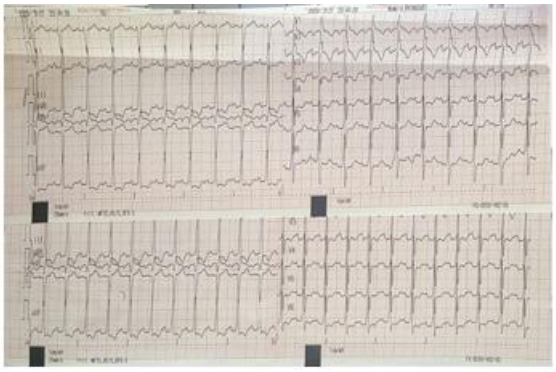

Figure 2: ECG at ER are consistent with Extreme Axis Deviation with right ventricular hypertrophy (RVH) and possible right atrial enlargement

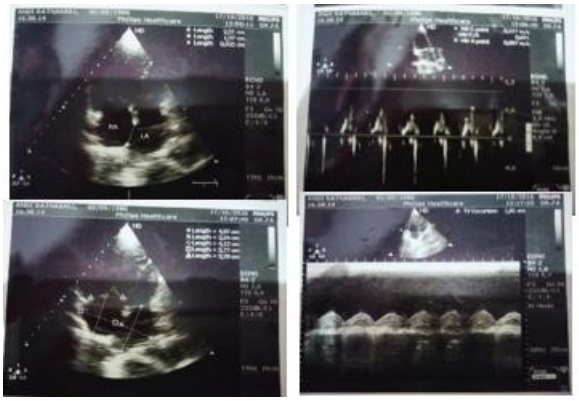

Figure 2: TTE before admission showing Secundum ASD (13.3 – 22.4mm) bidirectional shunt with RA & RV dilatation and D-Shaped LV; eRAP 8-15mmHg

Trans Thoracal Echocardiography (TTE) reveals left ventricular hypertrophy, LV D-shape, dilatation of the right atrium and ventricle, ejection fraction 54%, global left ventricle normokinetics, severe tricuspid regurgitation TVG 82 mmhg, severe pulmonary hypertension, ASD secundum size 13.3mm – 22.4mm, est. RAP 8-15mmHg. TTE confirms the cardiomegaly finding in x-ray exam.

This patient was first diagnosed with secundum ASD in 2016 and the echocardiography showing secundum ASD with bidirectional shunt and mild pulmonary hypertension of 41mmHg.

Then underwent cardiac catheterization on 11st November 2019 with results.

Table 1: Oxygen Test

Pre O_2 Test			Post O_2 Test		
PARI	:	14,47	PARI	:	9,75
Flow Ratio	:	1,08	Flow Ratio	:	1,32
PVR/SVR	:	0,68	PVR/SVR	:	0,45

Right heart catheterization demonstrated a markedly elevated pulmonary-to-systemic resistance index (PARI) of 14.47 and a PVR/SVR ratio of 0.68, with a nearly balanced flow ratio (Qp/Qs = 1.08) prior to oxygen administration. Post-oxygen testing showed minimal improvement (PARI 9.75; PVR/SVR 0.45; Qp/Qs 1.32), indicating irreversible pulmonary vascular disease. The overall clinical and hemodynamic profile was consistent with Eisenmenger Syndrome.

On echocardiography performed on December 28, 2020, just prior to the patient being lost to follow-up due to pandemic-related restrictions, the report noted that the patient had:

- **mild MR** (MR ERO 0,1cm^2, MR vol 12ml, MR radius 0,3cm).
- **Severe TR** (TR VC 0,7 cm, TR Max PG 85mmHg, TR Vmax 4.6m/s, Hepatic Vein Systolic reversal (+)),
- **Pulmonal Moderate PR** (PR HT 234ms, Regurgitant Jet PR >1/3 RVOT), Pv Acct 85ms, PASP 93mmHg, MPAP 58.73 mmHg, high probability of PH,
- **RA** (RA Mayor 5,4cm, RA minor 4,2cm, RA area 23,9cm^2) **& RV dilatation** (RVDB 4,3cm)
- **eRAP: 8mmHg**
- **ASD secundum size 13,3mm- 22,4mm**

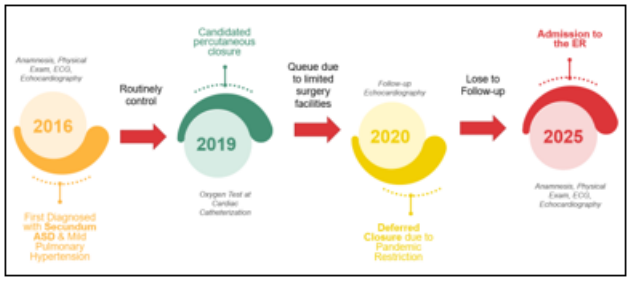

Figure 3: Timeline of Patient

Laboratory investigations in ER upon recent admission revealed an elevated white blood cell count of 17.5 × 10³ cells/μL (reference range: 4–9 × 10³ cells/μL), suggestive of bacterial infection, which was further supported by Gram stain examination. This was supported by Gram staining of the sputum specimen, which revealed Gram-positive cocci arranged in pairs at a low density of approximately 2 organisms per low-power field (LPF). The microscopic examination also showed 4 polymorphonuclear cells per high-power field (HPF) alongside occasional epithelial cells, consistent with an active inflammatory process. The patient's red blood cell count was elevated at 5.79 × 10⁶ cells/μL (reference range: 3.76–5.70 × 10⁶ cells/μL) with a hematocrit of 49.5% (reference range: 37–47%), findings suggestive of chronic hypoxia likely secondary to long-standing pulmonary hypertension. Serum electrolytes revealed significant hyponatremia (sodium 125 mmol/L, reference: 136–146 mmol/L) and mild hypochloremia (chloride 96 mmol/L, reference: 98–106 mmol/L). Such electrolyte abnormalities are commonly observed in patients with advanced pulmonary hypertension and right heart failure, attributed to neurohormonal activation including elevated antidiuretic hormone (ADH) secretion resulting in water retention and dilutional hyponatremia. Hypochloremia in this setting may be compounded by volume depletion, diuretic therapy, and acid-base disturbances linked to right ventricular dysfunction. These disturbances not only reflect disease severity but also carry prognostic significance.

Collectively, the clinical presentation and laboratory findings led to the diagnosis of severe pulmonary hypertension complicated by acute lung edema and bronchopneumonia with a Pneumonia Severity Index (PSI) score of 85, Secundum ASD, leukocytosis, and electrolyte imbalance.

Initial management comprised oxygen supplementation via a non-rebreathing mask to maintain oxygen saturation above 80%, addressing hypoxemia. Intravenous fluid therapy with 0.9% normal saline (500 mL over 24 hours) was administered cautiously to optimize right ventricular preload without inducing fluid overload. Intravenous furosemide was given as a 40 mg bolus followed by a continuous infusion at 5 mg/hour to manage volume overload and reduce right ventricular strain. Vasopressor support with norepinephrine (50–200 μg/kg/min) was initiated to maintain adequate systemic perfusion, while inotropic therapy with dobutamine (2–5 μg/kg/min) was used to enhance right ventricular contractility.

To address pulmonary vascular resistance, sildenafil (20 mg three times daily) was prescribed, alongside spironolactone (20 mg once daily) for aldosterone antagonism and further diuresis. Empirical antibiotic therapy with intravenous ceftriaxone (3 grams daily) was initiated to target the Gram-positive organisms observed on Gram stain. Additionally, a mucolytic agent (acetylcysteine injection) was administered to facilitate respiratory secretion clearance and improve airway hygiene during the acute pulmonary infection.

To manage the patient's hemoptysis, codeine 10 mg was administered twice daily. This intervention was crucial, as persistent coughing can exacerbate bleeding from fragile pulmonary capillaries, necessitating effective suppression to prevent further respiratory compromise.

Hypertonic saline (NaCl 3%) was also administered to aid in the correction of hyponatremia and hypochloremia. After the initial treatment in the ER, the patient were transferred to the cardiovascular care unit for continued monitoring and management.

On the second day of hospitalization, the patient remained on inotropic support and vasopressors to maintain hemodynamic stability. A continuous infusion of furosemide was administered via syringe pump at a rate of 5 mg/hour to manage volume overload. The patient also reported persistent nausea, for which ondansetron was administered intravenously three times daily for symptomatic relief.

On the third day of hospitalization, the sildenafil dose was uptitrated to 50 mg three times daily in response to persistent signs of pulmonary hypertension. Digitalis was also initiated at a dose of 0.125 mg once daily to improve right ventricular contractility and control heart rate. At the same time, the patient complained of chest and epigastric discomfort. Given the musculoskeletal nature of the pain and absence of ischemic ECG changes, symptomatic treatment with 500mg oral Paracetamol tablet three times daily was started. Additionally, the administration of hypertonic saline (3% NaCl) was discontinued, as serum sodium levels had stabilized and there was no further indication for continued correction of hyponatremia. On the fourth day, the digitalis dose was uptitrated to 0.25 mg once daily, along with downtitration of the inotropic and vasopressor, until finally being discontinued on the fifth day.

On the sixth day, the furosemide dose was tapered to 40 mg every 12 hours, further reduced to 20 mg every 12 hours on the seventh day, and subsequently transitioned to oral therapy at a dose of 40 mg once daily on the eighth day. Concurrently, ceftriaxone was discontinued after completing a seven-day course of antibiotic therapy.

After eight days of treatment, the patient achieved hemodynamic stability with minimal residual signs of congestion. The patient was discharged on the eighth day with a planned outpatient clinic follow-up scheduled oneweek post-discharge. No invasive intervention was planned during the hospitalization. Upon discharge, the patient was prescribed the following medications: furosemide 40 mg once daily, digoxin 0.25 mg once daily, codeine 10 mg twice daily, spironolactone 25 mg once daily, amoxicillin-clavulanic acid (amoxiclav) twice daily for five days, sildenafil 50 mg three times daily, and iron supplementation 60 mg once daily.

3. Discussion

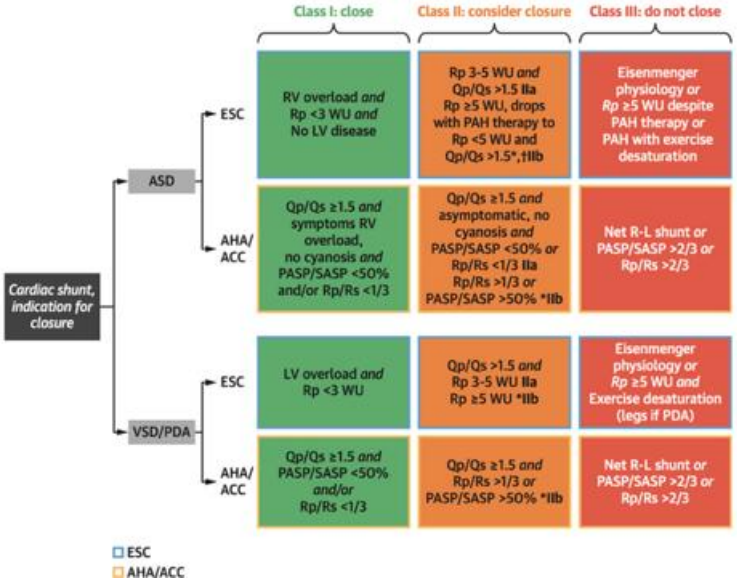

Figure 4: Recommendations Regarding Closure of Isolated Congenital Shunt Lesions.[1]

Eisenmenger syndrome represents the most advanced and severe form of pulmonary arterial hypertension (PAH) related to uncorrected congenital heart disease (CHD).[1,2] This condition typically arises in patients with longstanding left-to-right shunt lesions that have not undergone timely surgical or interventional closure. Initially, these lesions lead to volume overload of the pulmonary vasculature due to lower pulmonary vascular resistance compared to the systemic circulation.[2]

Over time, persistently elevated pulmonary blood flow initiates remodeling of the pulmonary vascular bed, characterized by vasoconstriction, medial hypertrophy, fibrosis, and in situ thrombosis. This pathological remodeling increases pulmonary vascular resistance, eventually reversing the direction of shunting to right-to-left. The reversal is driven by structural and functional changes in the pulmonary vasculature, which are influenced by imbalanced production of vasoactive substances including endothelin-1, thromboxane A_2, prostacyclin, and nitric oxide.[2,3]

Eisenmenger syndrome presents with extensive systemic involvement. Hallmark clinical features include chronic hypoxemia, compensatory secondary erythrocytosis often exacerbated by iron deficiency, frequent arrhythmias, recurrent infections, progressive heart failure, and a notably high incidence of renal dysfunction among patients with congenital heart disease.[4] In the present case, the patient exhibited classic signs of systemic desaturation: dyspnea at rest, central and peripheral cyanosis, digital clubbing, and laboratory evidence of erythrocytosis with elevated hemoglobin and hematocrit. Although secondary erythrocytosis enhances oxygen delivery, long-term oxygen therapy is not routinely indicated in Eisenmenger syndrome unless it demonstrates sustained improvement in oxygen saturation and symptom relief.[4,5] Indeed, supplemental oxygen administered in the Cardiovascular Intensive Care Unit (CICU) in our patient led to noticeable clinical and oxygenation improvements.

Severe pulmonary vascular pathology in Eisenmenger syndrome is relatively uncommon and influenced by multiple

factors including defect size, female sex predominance, age at presentation, and persistence of an uncorrected ASD. Genetic predisposition, similar to idiopathic PAH, may also contribute to disease progression. Early diagnosis and timely closure of ASD in infancy have drastically reduced the incidence of PAH.[6,7] For example, larger secundum ASDs have been identified in patients who progressed to Eisenmenger Syndrome.[7] In our patient, delayed presentation during the fourth decade of life combined with a large ASD (13–22 mm) strongly suggests that defect size was a primary determinant in the progression to severe PAH and eventual shunt reversal.

At the time of admission, our patient had bronchopneumonia and experienced hemoptysis due to cough that persisted on the second day of treatment. Hemoptysis represents a potentially life-threatening extracardiac complication in patients with Eisenmenger syndrome and pulmonary arterial hypertension associated with congenital heart disease (PAH-CHD). Although the reported prevalence of hemoptysis varies widely, studies suggest that it occurs in approximately 6% to 49% of Eisenmenger patients, with hemoptysis being the direct cause of death in about 3% to 11% of cases.[8,9] Older data by Wood reported mortality rates due to hemoptysis as high as 11.4%, while other historical series cite figures approaching 29.5%.[10] In our patient, the presence of acute bronchopneumonia likely contributed to clinical deterioration by increasing oxygen demand and precipitating decompensated heart failure. The inflammatory burden, combined with elevated pulmonary pressures and structural bronchial artery fragility, likely culminated in the hemoptysis observed during hospitalization. Adequate management of bronchopneumonia increases the survival rate in patients with Eisenmenger syndrome.[11]

According to the Pulmonary Hypertension Guidelines by the Indonesian Heart Association (PERKI), patients with PAH are at increased risk of respiratory tract infections, particularly pneumonia, which accounts for approximately 7% of deaths in this population. Although no randomized controlled trials have definitively proven benefit, current recommendations advise routine vaccination against influenza and *Streptococcus pneumoniae* in patients with PAH as a preventive measure.[12]

Initial management of non-productive cough in our patient included administration of codeine 10 mg as an antitussive agent. This approach is supported by existing literature, which recommends the use of cough suppressants as a first-line strategy in patients with hemoptysis to reduce mechanical stress and prevent further bleeding.[13] In cases of massive hemoptysis commonly defined as exceeding 200 mL in 24 hours or in recurrent episodes, further diagnostic work-up with chest CTPA is advised to identify the bleeding source. If a hypertrophied bronchial artery or other culprit vessel is identified, bronchial artery embolization (BAE) may be considered as a therapeutic option to control ongoing hemorrhage and prevent recurrence.[14]

According to the 2022 ESC/ERS Guidelines on the diagnosis and management of pulmonary hypertension, bosentan, an endothelin receptor antagonist is recommended for patients with Eisenmenger syndrome who exhibit symptoms, with demonstrated benefits in enhancing exercise tolerance, particularly improvement in six-minute walk distance (6MWD) and reduction in pulmonary vascular resistance (PVR), especially in those categorized under WHO Functional Class III.[15] Unfortunately, despite its established efficacy, bosentan remains unavailable in Indonesia to date.[12] As an alternative, macitentan, another endothelin receptor antagonist with improved receptor selectivity and tissue penetration, is currently available in Indonesia in the form of 10 mg film-coated tablets. The recommended dose is 10 mg once daily.[12,16] Due to the unavailability of macitentan at the treating facility, the patient's management was optimized using alternative pharmacological options accessible at the center.

Phosphodiesterase type 5 inhibitors (PDE5i) such as sildenafil and tadalafil have also shown favorable outcomes in both functional capacity and pulmonary hemodynamics in patients with PAH related to congenital heart disease, including Eisenmenger physiology. These agents inhibit the breakdown of cGMP thereby enhancing its vasodilatory effect and promoting relaxation of pulmonary vascular smooth muscle.[17,18]

Prostacyclin, a potent vasodilator primarily synthesized by the endothelium, exerts its effects throughout the vascular system. In addition to promoting vasodilation, it serves as a strong inhibitor of platelet aggregation and possesses cytoprotective and antiproliferative properties. In patients with PAH, dysregulation of the prostacyclin pathway is evident by the downregulation of prostacyclin synthase expression in pulmonary arteries, along with decreased levels of urinary prostacyclin metabolites.[20,21] In Indonesia, beraprost sodium is available in 20 mcg tablet formulation, with a recommended dosage ranging from 60 to 180 mcg per day, administered in three divided doses.[12]

In our case, digoxin was initiated shortly after discontinuation of intravenous inotropes. Traditionally, digoxin has been utilized as a positive inotropic agent in the management of right heart failure (RHF), particularly in the setting of right ventricular (RV) dysfunction.[22] Earlier studies reported a transient improvement in RV ejection fraction following digoxin administration. However, more recent meta-analyses have not shown consistent evidence of meaningful clinical or hemodynamic benefit.[23] Despite these inconclusive findings, digoxin continues to be used in selected cases of chronic RHF, often as an adjunctive therapy when signs of low output persist or in the presence of atrial arrhythmias.[12,13]

The assessment of operability in patients with congenital heart defects complicated by PAH requires careful hemodynamic evaluation to determine the potential benefit or risk of defect closure.[17] In this case, the patient underwent right heart catheterization with vasoreactivity testing using 100% oxygen. The results demonstrated a markedly elevated pulmonary vascular resistance index (PARI) of 14.47 pre-oxygen, which decreased only slightly to 9.75 post-oxygen administration. Similarly, the PVR/SVR ratio decreased from 0.68 to 0.45, but remained well above the threshold indicative of reversible pulmonary vasculopathy. The pulmonary-to-systemic flow ratio (Qp/Qs) was 1.08 pre-oxygen and increased modestly to 1.32 post-oxygen, suggesting the

absence of a significant left-to-right shunt and likely presence of net right-to-left shunting physiology.

These findings fulfill the hemodynamic profile consistent with Eisenmenger syndrome, characterized by fixed, non-reversible pulmonary vascular disease and right-to-left shunting. As outlined in the 2022 European Society of Cardiology (ESC)/European Respiratory Society (ERS) Guidelines for the Diagnosis and Treatment of Pulmonary Hypertension, closure of intracardiac shunts in this context is contraindicated. Specifically, patients with PVR ≥5 Wood Units (WU), PVR/SVR ≥2/3, or those with net right-to-left shunting fall into the Class III recommendation category, in which defect closure is not advised due to the risk of acute right ventricular decompensation.[12,17]

Figure 3 further illustrates the decision-making algorithm for congenital shunt closure based on combined ESC and AHA/ACC criteria. Our patient clearly aligns with the Class III (red box) category, which includes patients with Eisenmenger physiology or elevated pulmonary pressures and resistance that are non-responsive to vasodilator challenge. In such patients, the presence of a right-to-left shunt serves as a compensatory mechanism to offload the right ventricle. Surgical or percutaneous closure would eliminate this compensatory pathway, significantly increasing right ventricular afterload and predisposing to rapid clinical deterioration or death.[17]

Therefore, in accordance with current international guidelines and based on the hemodynamic data obtained, closure of the atrial septal defect in this patient was deemed contraindicated.[17] Long-term management should focus on optimization of pulmonary vasodilator therapy and supportive measures.[13]

In patients with atrial septal defect (ASD) who are contraindicated for defect closure, non-invasive supportive strategies become essential. Among these, micronutrient intervention, particularly iron supplementation, plays a crucial role. Secondary erythrocytosis in Eisenmenger syndrome is a compensatory physiological adaptation aimed at enhancing oxygen delivery in the setting of chronic hypoxemia. However, this mechanism is only effective when iron stores are sufficient to support erythropoiesis.[13]
Iron deficiency, resulting in impaired oxygen-carrying capacity despite elevated erythropoietin levels. Therefore, targeted iron therapy may be initiated to achieve optimal hemoglobin concentration relative to oxygen saturation, thereby improving tissue oxygenation and overall clinical status without inducing hyperviscosity.[13,24]

4. Conclusion

This case report reinforces the necessity of early detection and proactive management of atrial septal defects to prevent progression to Eisenmenger syndrome especially in healthcare systems affected by resource constraints or global health crises. The case further highlights the challenges of managing complex congenital heart disease in resource-limited settings, where delayed follow-up can result in irreversible pulmonary vascular pathology. A collaborative and multidisciplinary approach is essential for optimizing patient outcomes in similar cases.

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