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Single center experience with covered stent closure of sinus venosus atrial septal defect

Ata Firuzi[1], Zahra Khajali[2], Sedigheh Saedi[2], Mohammadreza Baay[1], Armin Elahifar[1], Abbas Talis[1], Hamidreza Pouraliakbar[3], Hooman Bakhshande[4], Elmira Aghaee Kiasaraee[1]✉, Mahboobeh Gholipour[1,5]✉ & Ehsan Khalilipur[1]✉

To evaluate the feasibility, safety, and short-term outcomes of transcatheter closure of sinus venosus atrial septal defect (SVASD) using covered stents. We conducted an institutional retrospective analysis of 24 consecutive patients aged 15–70 years with superior SVASD and significant left-to-right shunting (QP/QS ≥ 1.5), who underwent percutaneous closure using covered stents between June 2021 and December 2023. Pre-procedural imaging included transesophageal echocardiography and cardiac Computed Tomography angiography (CTA). Procedural details, technical success, and echocardiographic parameters were recorded. Post-procedural outcomes were assessed with transthoracic echocardiography and/or CTA. The Patients' median age was 38 years (IQR: 28–53), and 50% were female. Median Atrial Septal Defect (ASD) size was 15 mm (IQR: 11–19), and median QP/QS ratio decreased from 1.8 (IQR: 1.7–1.95) to 1.1 (IQR: 1.0–1.25) after closure ($p < 0.001$). Covered stents were used in all cases, and 13 patients (54.1%) required additional non-covered stent support. Technical success was achieved in 96% of patients, with one case of device embolization requiring surgical intervention. Minor complications occurred in 7 patients (29.1%), including hematoma and asymptomatic thrombosis. No mortality was observed. At 3 months, right ventricular dysfunction and enlargement significantly improved ($p = 0.004$ and $p = 0.001$, respectively), while right atrial size remained unchanged ($p = 0.317$). Catheter-based repair of SVASD is feasible, safe, and effective with a low rate of complications. This approach may offer a minimally invasive alternative to surgery in anatomically suitable patients.

Keywords Sinus venous atrial septal defect, Transcatheter closure, Covered sten

Sinus venosus atrial septal defect (SVASD), first described in 1858, constitutes approximately 4% to 11% of atrial septal defects (ASDs)[1]. This condition is characterized by a defect in the connection between the superior vena cava (SVC) and the right atrium (RA). Additionally, it involves abnormal drainage of the pulmonary veins into the RA, either directly or indirectly via the SVC, rather than the normal drainage into the left atrium (LA)[2]. This anomaly typically results in the caval veins extending over an intact atrial septum, which can lead to partial anomalous pulmonary venous drainage (PAPVD)[3]. Traditionally, treatment options were largely confined to open-heart surgery, which typically involved the closure of the defect with a patch. However, in 2013, Prof. Abdullah and colleagues introduced a novel transcatheter technique for SVASD correction utilizing a covered stent[4]. This innovative approach has been adopted internationally, with various modifications leading to consistently favorable outcomes[5–7].The objective of this paper is to evaluate our institutional experience with a series of 24 patients who underwent transcatheter correction for SVASD, focusing on the safety and efficacy of the procedure, identifying predictors of success, and documenting any associated complications.

[1]Cardiovascular intervention research center, Rajaie cardiovascular medical and research institute, Tehran 1995614331, Iran. [2]Congenital heart disease research center, Rajaie cardiovascular medical and research institute, Tehran 1995614331, Iran. [3]Cardiovascular imaging research center, Rajaie cardiovascular medical and research institute, Tehran 1995614331, Iran. [4]Cardiovascular epidemiology research center, Rajaie cardiovascular medical and research institute, Tehran 1995614331, Iran. [5] Healthy Heart Research Center, Heshmat Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran. ✉email: elikia266@gmail.com; Drmgholipur@gmail.com; Ehsankhalilipur@gmail.com

Method

Study design and population

This retrospective single-center case series included patients diagnosed with SVASD and PAPVD who underwent transcatheter closure at Rajaie Cardiovascular Medical and Research Institute between June 2021 and December 2023. The study was approved by Rajaie Cardiovascular Medical Center Ethics committee (Ethics Code: IR.RHC.REC.1403.117), and adhered to Declaration of Helsinki and also, informed consent was obtained from all participants. All cases were discussed in a multidisciplinary team (MDT) meeting to assess anatomical suitability for transcatheter correction.

Inclusion criteria included

Age between 15 and 70 years.

- Symptoms attributable to SVASD (e.g., dyspnea, palpitations).
- Evidence of significant left-to-right shunting (QP/QS ≥ 1.5).
- The presence of the right upper pulmonary vein (RUPV) had to be demonstrated to have dual drainage, meaning it connected to both the SVC and LA, ensuring preserved pulmonary venous return after stent placement.
- Adequate anatomical distance between the lower edge of the defect and the SVC-RA junction for stent anchoring.

Patients were excluded if the pulmonary veins drained entirely into the SVC without LA connection, or if stent placement risked obstruction of venous return.

Pre-procedural planning

Diagnosis and anatomical assessment were performed using transesophageal echocardiography (TEE) and cardiac computed tomography angiography (CTA)(Fig. 4-A).QP/QS ratios were calculated via Doppler echocardiography. Sizing of the defect and pulmonary veins was assessed on CTA and TEE. Hemodynamic balloon interrogation was used to confirm complete shunt elimination and unobstructed pulmonary venous return prior to stent deployment.

Intervention procedure

All procedures were performed under general anesthesia using dual venous access (right femoral and right internal jugular veins). A venovenous circuit was established using a 0.035-inch, 260-cm hydrophilic guidewire.

Two technical approaches were used:

1. Suture-based stent technique: In this method, two covered stents were sutured ex vivo using 2 – 0 silk sutures through designated eyelets. (Fig. 1-A) The assembly was delivered via jugular access, and the external end of the suture was secured to the skin at the neck to prevent stent migration.(Fig. 1-B).
2. Single stent technique: In the remaining patients, a previously reported technique was applied[8], but inverted with a single covered stent delivered and secured via external suture to the skin through the jugular access site.

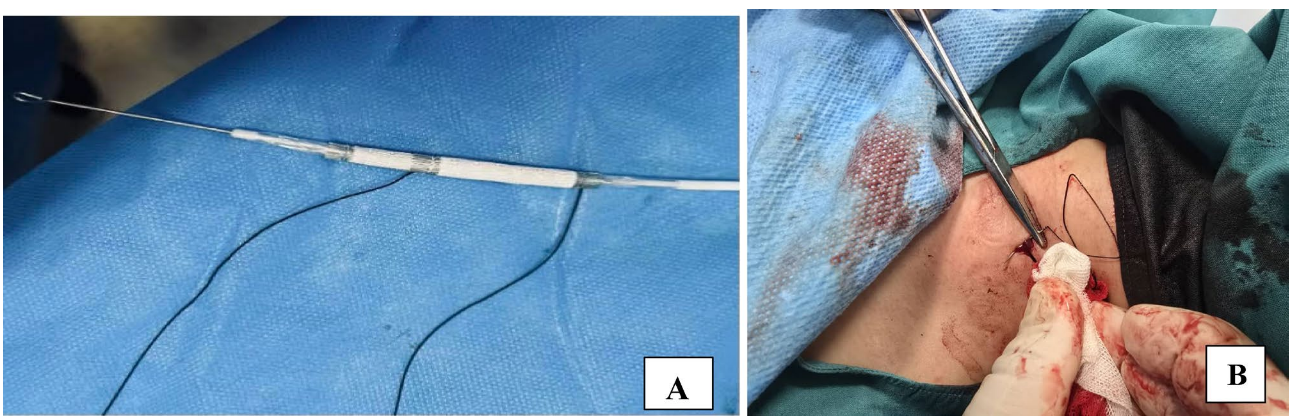

Fig. 1. Two sutured balloon-expandable 43 mm XXL covered CVS Optimus stents(**A**) and then Sutured to the skin at the neck (**B**).

Details of selected device

We employed a selection of covered stents, specifically the Optimus CVS XL and XXL variants, with dimensions of 38, 43, 48, and 57 mm (AndraTec GmbH, Koblenz, Germany)[9]. These stents were mounted on BiB® and TYSHAK® balloons (NuMED Corporation, Hopkinton, NY) or the Altosa®-XL-GEMINI (AndraTec GmbH, Koblenz, Germany) or the CP 8 zig 4.5 cm stent (NuMED Corporation, Hopkinton, NY), depending on the specific anatomical requirements. Notably, 13 patients (54.1%) benefited from the reinforcement of structures using non-covered stents, such as the CP 8 zig variants measuring 3.9–4.5 cm (NuMED Corporation, Hopkinton, NY).

Procedural overview

Under general anesthesia, venous access was established through three distinct routes: a 14 French, 80 cm sheath (Occlutech Intl, Helsingborg, Sweden) was inserted into the right femoral vein, a 12 French, 30 cm sheath (Abbott, Plymouth, MN, USA) was placed in the right jugular vein, and a 6 French, 7 cm sheath (Tabeeb Darmaan Pajouhesh Ghalb Co, Tehran, Iran) was introduced into the left femoral vein. Two approaches were utilized for the closure of the Superior Vena Cava Atrial Septal Defect (SVASD): a technique based on sutures, and a method that did not involve suturing.

An angiographic evaluation of the RUPV was conducted with and without inflating a balloon in the SVC to confirm that the RUPV was properly channeling blood back to the LA. Additionally, a frontal projection angiogram of the SVC was performed to ascertain the vein's diameter, particularly where it enters the RA. A properly sized balloon catheter was then inserted into the SVC and inflated while extending slightly into the RA, halting flow through the defect as monitored by TEE, thereby isolating the SVC from the RUPV. Simultaneously, a multipurpose catheter was introduced via the left femoral vein across the defect to the RUPV to conduct an angiogram in the four-chamber view, both before and after balloon inflation, ensuring that the contrast medium continued to drain into the LA. This was verified by injecting agitated saline into the RUPV under TEE observation, showing bubbles transitioning from the RUPV to the LA with no remaining shunt. While the balloon was inflated, a cine fluoroscopy image was captured, serving as a reference point for the placement of the covered stent.

In the suture-based technique, a 260 cm, 0.035-inch hydrophilic guide wire (Tabeeb Darmaan Pajouhesh Ghalb Co, Tehran, Iran) was threaded through the right femoral vein access and captured using a snare from the right jugular vein. Subsequently, a sizing balloon was inflated at the RA-SVC junction to match the SVC dimensions, while simultaneous TEE and angiographic visualization were performed in the Partial Anomalous Pulmonary Venous Connection (PAPVC) to determine the most suitable stent size and optimal deployment location for ASD coverage without compromising the pulmonary veins (Fig. 2-A).

Stent delivery via jugular access was initiated following confirmation of the appropriate stent size and deployment site. In all cases except three, where two covered stents were pre-attached ex vivo, a single covered stent secured to a suture was loaded and crimped onto a balloon (Fig. 3). This assembly was then inserted through a 14 French sheath, as it was unable to pass through a 12 French sheath, and was partially extended at the RA-SVC junction. TEE was utilized to monitor ASD coverage, allowing for positional adjustments of the stent by manipulating the attached suture. The stent's distal end was flared within the RA using either the initially mounted balloon or an alternative one (Fig. 2-B). Additional covered stents were deployed if the initial stent placement did not achieve satisfactory coverage. The stability of the covered stent was maintained by anchoring its proximal end to the SVC with an uncovered stent, which was also inserted through the 14 French sheath (Fig. 2-C). Post-dilation was performed under angiographic and TEE imaging guidance to ensure optimal stent apposition (Fig. 2-D). The final assessment involved evaluating SVC flow and pulmonary vein drainage during the levo phase (Fig. 2-E).

Post-procedural care and follow-Up

Patients received dual antiplatelet therapy (aspirin and clopidogrel) for one month, followed by aspirin monotherapy for five months. Transthoracic echocardiography (TTE) was performed before discharge and at three-months follow-up. CTA (Fig. 4-B) or TEE was performed postoperatively in selected patients based on clinical findings or suspicion of thrombus or residual defect.

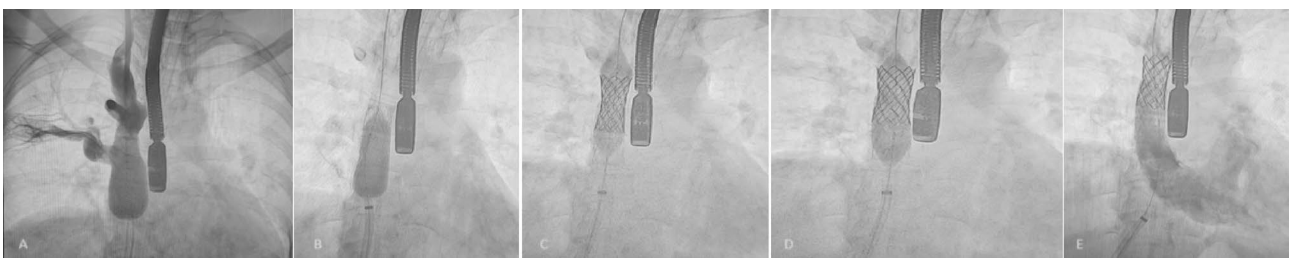

Fig. 2. Angiographic procedure (**A**) Sizing balloon inflation (**B**) Covered stent delivery and distal flaring (**C**) Non-covered stent delivery (**D**) Post-dilation balloon (**E**) Final result.

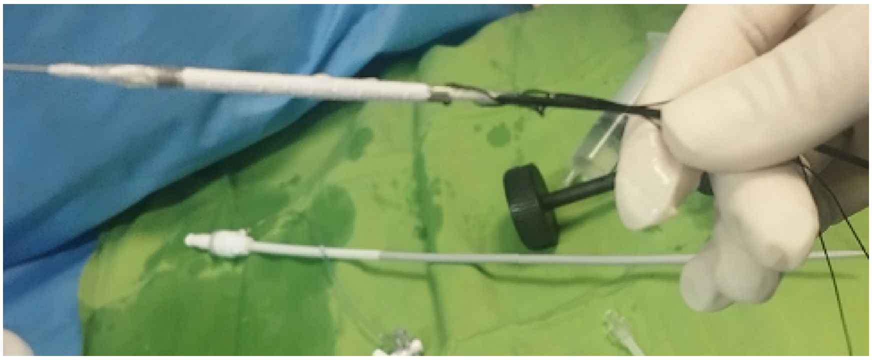

Fig. 3. Crimped covered stent attached to an absorbable suture.

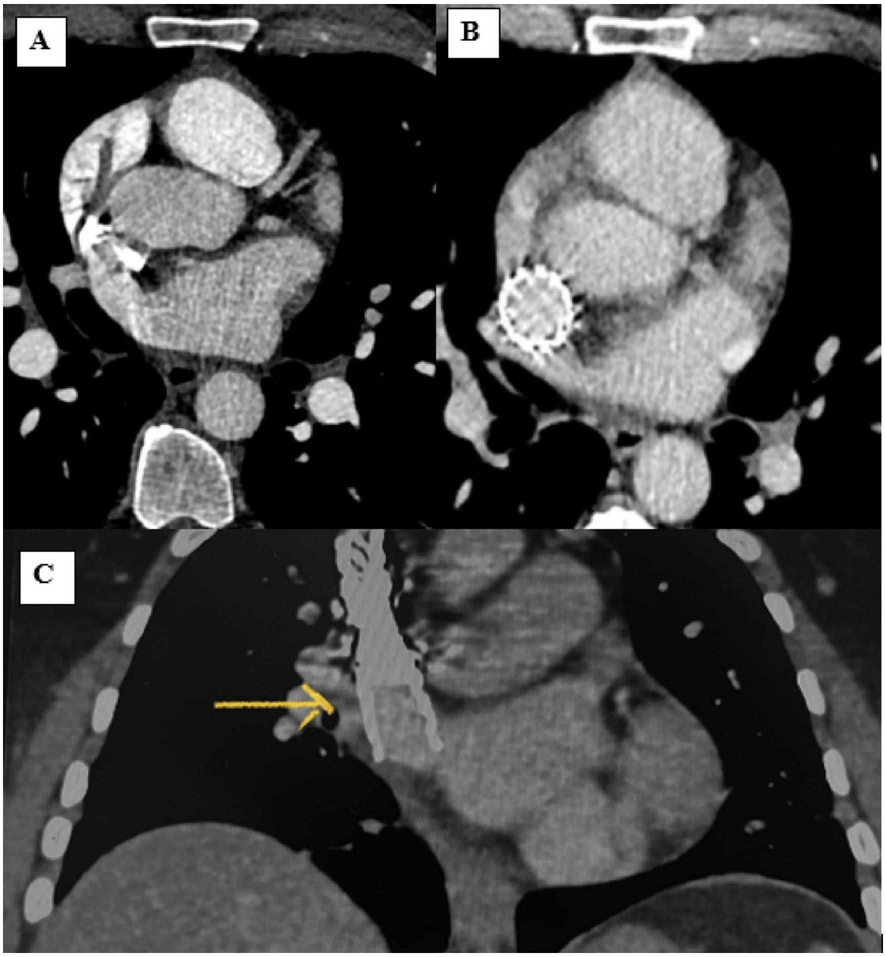

Fig. 4. Pre-procedure Cardiac CT scan with contrast (**A**). Post-procedure Cardiac CT scan without contrast (**B**).Non-obstructed thrombosis in Cardiac CT in hospitalization.(**C**).

Statistical analysis

Continuous variables are presented as median with interquartile range (IQR). Categorical variables are shown as counts and percentages. Pre- and post-procedural data were compared using the Wilcoxon signed-rank test. A p-value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA).

Patient Demographics	Mean/No (%)
Age(yr.)	36.6 (15–70)
Sex Female Male	12(50.0) 12(50.0)
BSA Female Male Diabetes HTN CVA or TIA COPD CKD	1.66 (1.6–1.8) 1.92 (1.8–2.2) 4 (16) 8 (33.3) 1(4.2) 0 0
Symptom Dyspnea Atypical chest pain Palpitation	15 (62.5) 4 (16.6) 5 (20.8)
ECG Normal INCOMPLETE RBBB COMPLETE RBBB INCOMPLETE RBBB + PAC	1(4.2) 14(58.3) 7(29.1) 2(8.3)

Table 1. Patients Demographic, clinical and electrographic characteristics. "Mean (maximum-minimum). BSA: Body Surface Area, CVA: Cerebrovascular accident, COPD: Chronic Obstructive Pulmonary Disease, CKD: Chronic Kidney Disease, HTN: Hypertension, TIA: Transient Ischemic Attack.

Characterestics	Value
ASD Size, mm	Median: 15 (IQR: 11–19)Range: 5–27
SVC Diameter at RA junction, mm	Median: 28.3 (IQR: 25–32)Range: 20–37
SVC Diameter at azygos level, mm	Median: 17.9 (IQR: 15–21)Range: 10–22
Most significant PAPVC distance to RA, mm	Median: 22.9 (IQR: 21–25)
PAPVC Type	RUPV only: 2 (8.3%) RUPV + RMPV: 22 (91.7%)
QP/QS Ratio	Median: 1.94 (IQR: 1.5–3.0)
SPAP, mmHg	Median: 38.5 (IQR: 34–45)Range: 25–60
Associated Anomalies	Left SVC: 4 (16.6%) Left PAPVC: 1 (4.1%) PFO: 1 (4.1%) Moderate–severe PS: 2 (8.2%) Previous ASD closure: 1 (4.1%) None: 15 (62.5%)

Table 2. Defect characterestics based on CT angiography and Echocardiography. PAPVD: Partially Anomalous Pulmonary Venous Drainage, SVC: Superior Vena Cava, ASD: Atrial Septal Defect.

Result
Patient demographics
A total of 24 patients (12 males, 12 females) underwent transcatheter closure of superior SVASD. The median age was 38 years (IQR: 28–53). Common presenting symptoms included dyspnea in 62.5% ($n = 15$), palpitations in 20.8% ($n = 5$), and atypical chest pain in 16.6% ($n = 4$). Electrocardiography showed incomplete right bundle branch block (RBBB) in 58.3% ($n = 14$), complete RBBB in 29.1% ($n = 7$), and normal findings in 4.2% ($n = 1$). One patient had a prior secundum ASD device closure and another had a history of severe pulmonary stenosis requiring balloon valvuloplasty prior to the procedure.(supplementary Table 1) (Table 1).

Defect characteristics
The median ASD size was 15.0 mm (IQR: 11–19), and the SVC diameter at the RA junction measured 28.3 mm (IQR: 25–32). The QP/QS ratio before the procedure was 1.8 (IQR: 1.7–1.95). All patients had PAPVD; 91.6% ($n = 22$) had both RUPV and right middle pulmonary vein (RMPV) involvement, while 8.3% ($n = 2$) had isolated RUPV involvement. The most significant anomalous pulmonary vein was located a median of 22.9 mm (IQR: 21–25) from the SVC-RA junction. (Table 2)

Procedural details
Covered stents were used in all patients (100%). In 3 cases (12.5%), two covered stents were sutured ex vivo before delivery (Fig. 1). The suture-based anchoring technique (securing the stent to the skin) was used in 66.7% ($n = 16$) of cases.

Parameters	No (%)
Covered stent Noncovered stent	24(100) 13(54.1)
Double stent Novcovered stent Covered stent	13(54.1) 3(12.5)
Post-dilation	21(87.5)
Flaring balloon	21(87.5)
Neck suture	16(66.7)
Jugular/femoral access	24(100)
Figure of 8 for access site closure	24(100)
Supporting hydrophilic wire	24(100)
No other procedures PTPC (before procedure) ASD secundum closure device (after procedure)	22(91.6) 1(4.2) 1(4.2)

Table 3. Procedural details during and after procedure. PTPC: Percutaneous Transcatheter Pulmonary Commisurotomy.

Echocardiographic data	(Q1-Q3) before	(Q1-Q3) after	*P* value
QP/QS	1.8(1.7–1.95)	1.1(1-1.25)	< 0.001
SPAP (mmHg)	37(34.5–40)	35(30–35)	0.01
EF (%)	55(55–55)	55(55–55)	> 0.999
ASD size(mm)	15(11–19)	3(0-5.5)	< 0.001

Table 4. Quantitative echocardiographic data before and after the procedure. Significant P value defined as < 0.05. SPAP: Systolic Pulmonary Arterial Presssure, EF: Ejection Fraction.

Echocardiographic data	No (%) Before	No (%) After	*p*-value
RV Function Normal Preserved Mild dysfunction Mild to moderate dysfunction Moderate dysfunction	5(20.8) 7(29.1) 7(29.1) 3(12.5) 2(8.3)	11(45.8) 2(8.3) 9(37.5) 1(4.2) 1(4.2)	0.004
RV enlargement Mild Mild to moderate Moderate Moderate to severe Severe	5(20.8) 5(20.8) 5(20.8) 4(16.7) 5(20.8)	8(33.3) 8(33.3) 5(20.8) 2(8.3) 1(4.2)	0.001
RA enlargement No Mild Moderate Severe	10(41.6) 10(41.6) 1(4.1) 3(12.5)	11(45.8) 9(37.5) 1(4.2) 3(12.5)	0.317

Table 5. Qualitative echocardiographic data before and after procedure.

Technical success was achieved in 23 of 24 patients (96%). One case experienced device embolization requiring conversion to surgical repair. No mortality or major bleeding occurred. (supplementary Table 2) (Table 3).

Echocardiographic results

Statically significant improvements were observed in the primary echocardiographic parameters following the intervention, as demonstrated by both quantitative and qualitative outcomes. The QP/QS ratio notably decreased from a median of 1.8 pre-intervention to 1.1 post-intervention ($P < 0.001$). Additionally, there was a substantial reduction in the size of the ASD, which decreased from an average of 15 mm before the procedure to 3 mm afterward ($P < 0.001$). The systolic pulmonary artery pressure (SPAP) also exhibited a reduction, decreasing from 37 mmHg (range: 34.5–40 mmHg) to 35 mmHg ($P = 0.01$).(supplementary Table 3) (Table 4).

In the qualitative assessment, both right ventricular (RV) function and size showed marked improvement, with significant decreases noted post-procedure. However, changes in right atrial (RA) size did not reach statistical significance. (Table 5)

Complications	No (%)
No complication	16(66.7)
Minor Femoral hematoma Jugular hematoma Right SVC thin thrombosis	 3(12.5) 3(12.5) 1(4.2)
Major Device embolization	1(4.2)

Table 6. Complications during and after procedure.

Post-procedural complications and follow-up outcomes

The median hospital stay was 3 days. Minor complications were noted in 7 patients (29.1%), including femoral hematoma ($n=3$), jugular hematoma ($n=3$), and non-occlusive thrombus in the right SVC($n=1$) which detected on CTA and treated with intravenous anticoagulation in hospitalization and after discharge underwent Apixaban and Clopidogrel for six months. (Fig. 4-C). (Table 6)

At three-months follow-up:

- QP/QS ratio significantly decreased from 1.8 (IQR: 1.7–1.95) to 1.1 (IQR: 1.0–1.25) ($p<0.001$).
- ASD size decreased from 15 mm (IQR: 11–19) to 3 mm (IQR: 0–5.5) ($p<0.001$).
- SPAP reduced from 37 mmHg (IQR: 34.5–40) to 35 mmHg (IQR: 30–35) ($p=0.01$).
- RV dysfunction improved significantly ($p=0.004$).
- RV enlargement improved in most patients ($p=0.001$).
- No significant change in RA size was observed ($p=0.317$).

Ejection fraction remained stable (median: 55%).

Furthermore, Antiplatelet therapy included dual therapy (aspirin + clopidogrel) for one month followed by aspirin alone for five months was continued. Also, in one patient due to non-occlusive thrombosis Apixaban plus Clopidogrel was continued for 6 months.

Discussion

Transcatheter devices have become standard practice for the closure of secundum ASDs; however, the management of SVASDs has historically relied on surgical methods involving cardiopulmonary bypass. Recent technological advancements have begun to change this approach. Walker et al. demonstrated that surgical repairs of SVASDs tend to be more complex than those for isolated secundum ASDs and carry potential risks, including sinus node dysfunction, residual atrial shunting, and obstruction of the SVC and/or pulmonary veins[10]. The transcatheter correction of SVASDs accompanied by PAPVD represents a challenging interventional technique, necessitating thorough, multidisciplinary planning before the procedure. This technique was first introduced by Abdullah et al. at a CSI conference in 2013, which subsequently encouraged its adoption at our institution[4]. The procedure has shown favorable immediate, short-term, and mid-term outcomes. Hansen et al. provided insights from a median follow-up of 1.4 years in 25 adult patients who underwent transcatheter closure of SVASDs. During this follow-up, it was confirmed that the SVC stents were appropriately positioned, with both TTE and computed tomography (CT) scans demonstrating patency of the pulmonary venous flow[2].

Successful performance of the transcatheter closure for treating SVASDs hinges upon certain critical anatomical features. A key requirement is the presence of an unobstructed, normal-sized SVC. Additionally, the RUPV and/or RMPV must have a direct connection to the LA. A meticulous assessment of the size, number, and positioning of the anomalously draining pulmonary veins is essential. In cases, where an accessory or elevated RUPV drains into the SVC rather than the LA pose considerable challenges; if both the RUPV and RMPV drain exclusively into the SVC without interconnection to the LA, a transcatheter approach is typically unviable due to the significant risk of pulmonary vein stenosis. Surgical redirection may be a more appropriate solution for large pulmonary veins that solely drain into the SVC above the atrial junction due to the risks associated with venous compression by stents. Moreover, a significant caudal displacement of the defect near the atrial septum may hinder the effectiveness of transcatheter closure. The optimal anatomical configuration for a transcatheter approach lacks any caudal extension, with RUPV drainage confined to the cavoatrial junction. A thorough evaluation of these elements is crucial for optimizing patient outcomes and minimizing the possibility of adverse effects.

Worldwide, the procedure is performed using various pre-procedural imaging techniques, including cardiac MRI, 3D printing, and augmented as well as virtual reality technologies[2,5,11–13]. However, the implementation of these advanced modalities often requires considerable infrastructure investments, which may be cost-prohibitive for many institutions[14]. Furthermore, the availability of such sophisticated tools is limited in numerous developing countries, where the demand for corrective procedures significantly surpasses the resources available. While the optimal imaging modality remains a topic of ongoing discussion, data obtained from TEE appears sufficient to initiate the procedure[14].

In our study, we utilized coronary CTA before the procedure, while TEE was employed for intra-procedural guidance. Post-procedure, TTE was used for patient monitoring, with CCTA or TEE performed based on reported symptoms. We observed a reduction in the QP/QS ratio from 1.8 to 1.1 and a decrease in the average size of the ASD from 15 mm to 3 mm. These findings are consistent with reports from other studies; for example, Hejazi et al. indicated a decline in the QP/QS ratio from 2.04 to 1.04 among 14 patients, while Rosenthal et al. noted a reduction from 2.5 ± 0.5 to 1.2 ± 0.36 in a cohort of 75 patients[15,16]. These results underscore the effectiveness of transcatheter interventions in significantly reducing shunt volumes. Despite a statistically significant decrease in SPAP decreased from 37 mmHg to 35 mmHg ($p = 0.01$), no clinical reduction was observed. This suggests that although there was a clinical reduction in volume shunt, additional follow-up may be necessary to achieve a decrease in SPAP.

The accurate measurement of both the diameter and length of the selected covered stent is crucial, particularly as one must consider the potential shortening of the stent—especially at the lower end due to flaring—when determining the appropriate length. In our procedures, we utilized the Optimus (AndraTec GmbH, Koblenz, Germany) and Zig covered Cheatham-Platinum (NuMED Corporation, Hopkinton, NY) stents, which have demonstrated acceptable outcomes in previous studies and were deemed appropriate for our patient population[16–18]. Furthermore, Optimus stents due to reliable mechanical behavior and covering design are suitable for simple and complex congenital heart disease[19].

It is noteworthy that device embolization occurred in one patient where neck sutures were not employed, resulting in the necessity for open surgery. However, all other procedures were completed without any life-threatening complications. Following the embolization incident, neck sutures were utilized in 16 (66%) patients, providing a new strategy that effectively prevented device migration and embolization, allowed for better alignment of the stent, offers greater control over stent positioning, residual shunting in transcatheter closure of SVASD consistent with favorable results reported in other studies[6,15].

Sivakumar et al. documented three comparable cases in their research: two patients required surgical intervention, while the third was successfully treated through a non-surgical approach utilizing an overlapping covered stent[14]. This demonstrates the importance of overnight hospitalization post-procedure, alongside standby surgical support. Despite the absence of balloon protection in our patients, we observed no incident of stricture formation in the pulmonary vein. Balloon protection, as employed in a study conducted in India, serves to prevent the closure of pulmonary artery during stent implantation[20]. In addressing this defect, we primarily utilized one or two balloon-expandable covered stents; however, self-expandable stents, as used by Kannan et al., represent an additional viable option for defect coverage[21].

We implemented dual antiplatelet therapy for one month, followed by aspirin (ASA) for an additional five months. In one case, a thin, asymptomatic thrombotic layer behind the stent in the SVC was identified via coronary CT angiography. Comparatively, Sagar et al. identified asymptomatic thrombi in four patients through routine transesophageal echocardiography surveillance, all of whom had dual SVC drainage[20]. The first patient presented with a pedunculated nonocclusive thrombus at the atrial end of the stent, while the other three had thrombi located in the mid-section of the atrial segment. However, the study by Kannan et al. indicated that post-procedural CT scans were more effective than TEE and TTE for the early detection of thrombosis[21]. This finding emphasizes the importance of maintaining a high level of suspicion and employing multiple imaging modalities to ensure accurate diagnosis, particularly if the patient continues to exhibit symptoms or experiences a recurrence. The patient was conservatively managed with anticoagulation therapy.

Surgical intervention for SVASD has long been established as the conventional treatment approach. Although surgical repair generally shows a low incidence of complications, it is not devoid of significant risks, which include those associated with sternotomy and cardiopulmonary bypass, as well as specific concerns such as sinus node dysfunction occurring in 2% to 8.6% of patients, often necessitating pacemaker implantation, and obstructions of the pulmonary veins and SVC, reported in 2.7% to 7.7% of cases[22]. Our study demonstrated a commendable success rate of 96%, with no mortality related to the procedure. In comparison, similar transcatheter studies highlight its therapeutic efficacy, with Sivakumar achieving nearly 92% success[14], Sagar at 97%[20], Hansen at 92%[2], and Rosenthal at approximately 95%[16]. These findings suggest that transcatheter correction not only matches but may surpass the efficacy of traditional surgical methods, supported by its success rates and potentially reduced complication profiles.

The development of specialized stents, such as the VB self-expandable and Jove stents, represents a significant advancement in addressing complex cardiovascular conditions, including SVASD. Constructed from advanced materials like nitinol, these stents exhibit exceptional flexibility, shape memory, and biocompatibility, facilitating precise deployment and optimal adaptation to complex anatomical structures (16). In contrast, traditional balloon-expandable stents, such as the Covered CP stent, provide robust radial strength but may be limited in their ability to conform to dynamic or irregular vascular geometries. This evolution highlights a broader industry trend towards patient-specific solutions, with an emphasis on the development of specialized stents that enhance clinical outcomes in challenging cases. Leading manufacturers are driving this innovation, focusing on tailored technologies that meet the unique requirements of complex cardiovascular interventions.

Procedures are performed globally using various techniques; however, certain steps may enhance outcomes and reduce complications, necessitating further research for confirmation. These include: (1) the use of neck sutures, (2) balloon protection in PAPVC, (3) post-procedural CT scans, and (4) short-term post-procedural anticoagulation. This procedure presents a viable alternative to open surgery. It is important to highlight that the inaugural instance of direct stent implementation in the pulmonary vein for the repair of PAPVC in the United States was conducted recently[23].

Limitations

Several limitations should be acknowledged. First, the study was retrospective and conducted at a single center, limiting generalizability. Second, routine post-procedural CT was not performed in all patients, potentially underestimating thrombus formation. Third, the follow-up duration was limited to three months; long-term outcomes, including late thrombus, restenosis, or residual shunting, require ongoing evaluation. Fourth, we did not include a comparator surgical cohort. Future studies with prospective designs, longer follow-up, and comparative analysis are needed.

Conclusion
Catheter-based repair of SVASD is feasible, safe, and effective with a low rate of complications. This approach may offer a minimally invasive alternative to surgery in anatomically suitable patients

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to E.A.K., M.G. or E.K.

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