Assessment of morphological and hemodynamic changes in adult atrial septal defect before and after percutaneous trans-catheter closure: the initial result in Vietnamese patient

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Abstract. – OBJECTIVE: This study aimed to evaluate the change of morphology and hemodynamics in a relatively large number of patients with atrial septal defect (ASD) and provide the initial result in Vietnamese patients.

PATIENTS AND METHODS: This longitudinal, prospective case-control study was done at the Vietnam National Heart Institute from January 2012 to December 2017. The participants were divided into two groups: the ASD group, which included patients with ASDs, and the control group, which included healthy individuals or individuals without cardiac-related disorders.

RESULTS: There were 94 participants in the ASD group and 83 participants in the control group. Most patients with ASDs in the study group were female, and the average age was 38.65 ± 14.8. The success rate of the ASD group was 98.9%. The right ventricle morphology and function showed right ventricular diameter, pulmonary trunk gradually decreased, FAC and ET increased, IVCT and IVRT decreased, and Tei index gradually decreased after each examination. Morphology and function of the left ventricle after ASD closure showed that the left ventricular diameter gradually increased, and EF% in 3 months after ASD closure increased statistically significantly. IVCT, IVRT, and LV Tei index decreased, and ET increased statistically significantly. After six months from ASD closure, the proportion of patients with NYHA I was 90.3%, with no patient with NYHA IV, and pulmonary vascular resistance gradually decreased.

CONCLUSIONS: Percutaneous trans-catheter closure in Vietnamese adult atrial septal defect was an effective technique. Ventricle morphological and hemodynamic abnormalities following closure recovered statistical significance over time, particularly in the left ventricle.

Key Words:
Atrial septal defect, Percutaneous transcatheter closure, Vietnamese patients, Morphology, Hemodynamic.

Introduction

One of the most prevalent heart defects among patients with congenital heart disease is atrial septal defect (ASD), of which the majority have secundum ASD[1]. Congenital cardiac disorders are classified based on the clinical impact of anatomical anomalies on blood circulation physiology[2]. Asia reported the highest congenital heart disease (CHD) birth prevalence, with more pulmonary obstructions and fewer left ventricular outflow tract obstructions[3]. In the past, secundum ASD treatment was primarily accomplished through operational closure, but in recent decades, transcatheter closure has emerged as a viable alternative[4]. Secundum closure device ASD has gradually improved efficiency and lowered the likelihood of adverse events and mid- and long-term effects[5]. Currently, both operative and transcatheter closures are typically offered.

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While transcatheter closure is less invasive than operative closure, secundum ASD patient anatomical requirements exclude some patients from transcatheter closure treatment. Right ventricular (RV) dysfunction is closely related to patient outcomes in open and closed ASD[6]. Two-dimensional echocardiography has been widely used to assess right ventricular systolic function in ASD. The early period following transcatheter closure, using Amplatzer devices (Abbott Laboratories, IL, USA), showed a decrease in right heart chamber size and tricuspid annular velocities[7]. Right and left ventricular strain and strain rate[8] and longitudinal deformation[9] were also recorded. However, two-dimensional methods have certain limitations considering the right ventricle's complicated anatomy and irregular chamber shape[10].

Real-time three-dimensional echocardiography (RT3DE) is a recently introduced echocardiographic technique with the advantage of displaying the three-dimensional structure of the heart[11]. Previous studies[12] have validated the accuracy and reproducibility of RT3DE in evaluating RV global volume and systolic function. Recent studies[13] reported RT3DE's potential utility in assessing RV regional systolic function in different clinical settings. However, RT3DE in quantifying RV global systolic function in ASD has been addressed in limited studies with relatively small patient samples[14]. There is a lack of information about the analysis of morphological and hemodynamic changes in ASD patients before and after transcutaneous closure, especially in developing countries such as Vietnam. Therefore, this study aimed to evaluate the change of morphology and hemodynamics in a relatively large number of patients with ASD and provide the initial result in Vietnamese patients.

Patients and Methods

This longitudinal, prospective case-control study was done at the Vietnam National Heart Institute from January 2012 to December 2017. The participants were divided into two groups: the ASD group, which included patients with ASDs, and the control group, which included healthy individuals or individuals without cardiac-related disorders. The flowchart of the study showed in Figure 1.

ASD Group

In the ASDs group, the patient had to be over 16 to be seen by a doctor at the Vietnam National Heart Institute for a clinical examination, consultation, or treatment. Patients diagnosed with secundum atrial septal defect (ASD II) with one or more shunts, aged over 16 regardless of gender, were included in the study. They were unrelated to the clinical context of other congenital heart illnesses such as Lutembacher's syndrome, Ebstein's Anomaly, or Fallot Pentalogy. Patients who were diagnosed with ASD consented to participate in the investigation. Ages under sixteen, general atrium disorders, atrioventricular septal defect, ostium primum ASD, sinus venous ASD, coronary sinus ASD, and ASDs occurring in the clinical context of other congenital heart diseases were excluded.

Control Group

This group consisted of healthy individuals who visited the Outpatient Department of Bach Mai Hospital for routine screening or a health examination unrelated to heart disease and met the requirement; the average age and gender ratio

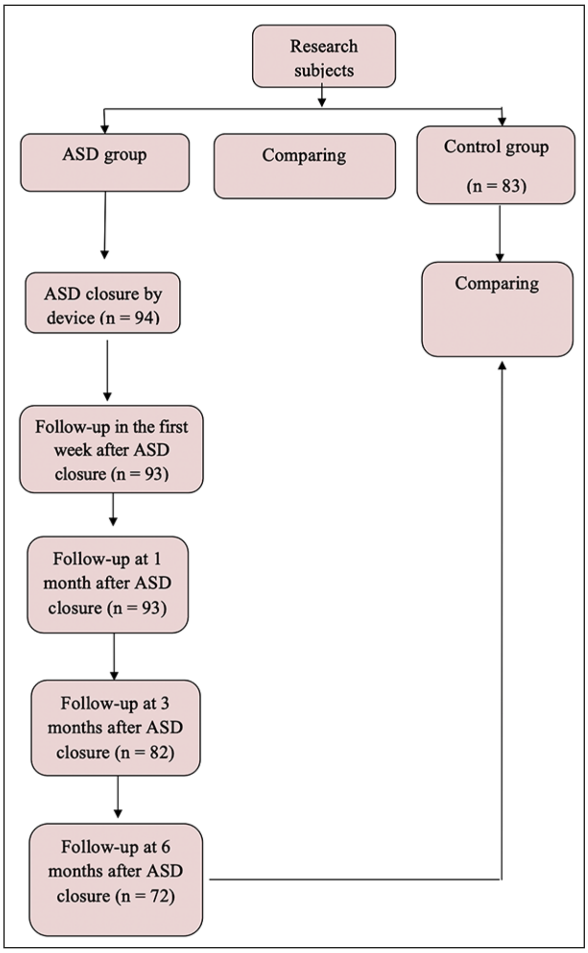

Figure 1. Flowchart of study.

of the control group were comparable to those of the ASD group (comparing the control group and ASD group regarding cardiac dimensions and functions).

Inclusion criteria included: (1) age more than or equal to 16 years old, (2) having good health or being diagnosed with diseases that do not affect cardiac functions such as degenerative spine disease, periarteritis humeroscapularis, urinary tract infection by clinical examination, electrocardiography, chest X-ray, Doppler echocardiography and complete blood count (CBC). The average age and the gender ratio were equivalents between the two groups; (3) undoubted echocardiographic image; (4) agreeing to participate in the study. Exclusion criteria included: (1) age under 16 years old and not equivalent to the ASD group; (2) being diagnosed with heart diseases such as congenital heart diseases, pericardial disease, valvular heart diseases (moderate to severe mitral valve regurgitation) coronary artery diseases or acute or chronic diseases affecting cardiac functions such as hypertension, COPD, anemia, acute kidney failure; (3) pregnant women, (4) low-quality images on transthoracic echocardiography, and (5) disagreeing to participate in the study were also excluded.

Diagnostic Criteria for ASDs

According to the European Society of Cardiology's (ESC) 2010 Guidelines, ASDs are mostly diagnosed *via* Doppler echocardiography. Our study utilized a Philips iE33 Cardiac Ultrasound Machine - WA 98021-8431-USA (Amsterdam, Netherlands) equipped with real-time 3-dimensional transthoracic echocardiography, Maxtrix, 3,5 MHz. Cardiovascular catheterization or heart surgery is the gold standard for confirming the diagnosis in eligible patients.

Three-Dimensional Echocardiography

The Transthoracic Doppler Echocardiography (TTDE) image shows a defect in the interatrial septum on two-dimensional echocardiography from apical four-chamber view and/or sub-costal view. Doppler with color shows a colorful flow getting through the defect. Pulsed Doppler shows a spectrum of low velocity ($\approx$ 1 m/s): a positive two-phase spectrum with one systolic peak and one diastolic peak in case of a left-to-right shunt, or a negative spectrum if it is a right-to-left shunt. At early ventricular systole, it is possible to record a tiny left-to-right shunt, which varies by respiratory phases and exists persistently throughout all cardiac circles. Transesophageal Echocardiography (TEE) is in line with trans-thoracic 2D echocardiography, but with a higher quality image and higher sensitivity and specificity. Diagnosed ASDs are based on the image of the defect in the inter-atrial septum and colorful flow across the defect. In case the defect and the color flow are not evident on the mentioned imaging modalities, contrast echocardiography (CE) is recommended (might be combined with Transesophageal or Transthoracic Doppler Echocardiography) to confirm the diagnosis. A patient is diagnosed with ASDs if one of the following is recorded: contrast microbubble washout image appearing in the right atrium in case of left-to-right shunt, a contrast agent-free region of the right atrium near the shunt, positive contrast image recorded in case of a bidirectional shunt or right-to-left shunt, contrast microbubbles travel from the right atrium to the left atrium naturally or after maneuvers increasing the pressure in right heart chambers, such as coughing or Valsalva maneuver. Ultimately, cardiac catheterization or heart surgery (in case patients meet indications) is a gold standard to confirm the diagnosis.

ASD II diagnostic criteria are determined *via* transthoracic, trans-esophageal, or real-time 3D echocardiography, according to the defect's location on the interatrial septum with cardiac structures. Cardiac catheterization and cardiac surgery are the gold standards for diagnosing ASDs categorically. A patient who did not indicate an ASD closure is in an acute state of one of the following diseases: unstable angina, myocardial infarction, infection, or uncompensated heart failure, or is suffering from a disease that impairs cardiac function, such as hypertension, COPD, anemia, acute kidney failure, or Beriberi diseases. Patients who were pregnant or who declined to participate in the trial were also excluded.

Research Parameters

Changes in morphological characteristics and imaging function during the investigation were observed. Doppler echocardiography was performed on all participants in both groups, but mainly on the patient ASD group, before, immediately following, and one month, three months, and six months after ASD closure. The disease group's parameters before and after six months from ASD closure were compared to the control group's parameters: diameter of the left ventricle at the end of diastole (Dd), at the end of systole (Ds), the volume of the left ventricle at the end of

Table I. The distribution of the study participants by age and gender groups.

Age group	ASD group (n = 94)				Control group (n = 83)				p-value
	Male (n %)		Female (n %)		Male (n %)		Female (n %)		
16 ≤ 25	6	6.4	12	12.8	6	7.2	6	7.2	> 0.05
25-39	8	8.5	23	24.5	9	10.8	18	21.7	
≥ 40	13	13.8	32	34	13	15.7	31	37.4	
Total	27	28.7	67	71.3	28	33.7	55	66.3	
$\bar{x}$ ± SD	38.65 ± 14.8				40.4 ± 14.4				> 0.05

diastole (Vd), at the end of systole (Vs), Fraction Shortening of LV (%D), Left ventricle ejection fraction (EF%), volume dilatation time (IVRT), volume contraction time (IVCT), ejection time (ET), muscle function index of LV (LV Tei), pulmonary artery pressure (PAP), pulmonary vascular resistance (PVR).

Statistical Analysis

Data were analyzed using SPSS v. 20.0 (Statistical Package for Social Sciences version 20.0, IBM Corp., Armonk, NY, USA) to determine correlations between MRI characteristics and pathological features. Differences were evaluated using the Mann-Whitney U test. Categorical variables were compared using the Chi-square test or Fisher's exact test. The *p*-values lower than 0.05 were considered significant.

Results

General Characteristics

There were 94 participants in the ASD group and 83 participants in the control group. The majority of patients with ASDs in the study group were female. The average age of the cases was 38.65 ± 14.8. The age group of 40 and over accounted for the highest proportion (47.8%), and the under-25 age group was 19.2%. The age and gender distributions of the cases were identical to those of the controls (Table I).

Symptoms, such as dyspnea, chest pain, and palpitations were frequently reported. 85,1% of patients with ASDs had a systolic murmur sound in the second left intercostal space, while 47.9% had a Split S2 sound at the apex cordis (Table II). Table III summarizes the subclinical characteristics of the ASDs group. 73.4% of patients had a regular sinus rhythm, while 55.3% had an incomplete right bundle block. Cardiomegaly (68.1%) and an enlarged pulmonary artery arch (69.1%) were detected on chest X-ray, as pulmonary circulation was increased (71.3%).

Table IV lists the parameters used to assess pulmonary hemodynamics and circulation. 72.4% had moderate to severe systolic pulmonary artery pressure (SPAP), whereas 39.3% had pulmonary vascular resistance index (PVRI) of 1.8. The PVRI and the Qp/Qs ratio were substantially higher in the cases group than in the control group. The success rate of the ASD group was 98.9% (92/93). There was one case with device placement failure because the margin of the inferior vena cava was short, thin, and flexible. The complications after device closure were minor. There was one case with arrhythmias and one with a mild residual shunt. Table V shows the changes in morphology and function of the right ventricle before and after ASD closure. Right ventricular diameter and pulmonary trunk gradually

Table II. Clinical symptoms of ASDs group (n = 94).

Characteristics	Number (n)	Percentage (%)
Dyspnea	51	54.2
Chest pain	54	57.4
Palpitationsa	48	51.1
Fainting or near fainting	9	9.6
Harzer signs	4	4.3
Enlarged liver	5	5.3
Moist rale	5	5.3
Systolic murmur at the second left intercostal space	80	85.1
Split S2	45	47.9
Systolic murmur at the 5th left mid-clavicular intercostal space	24	25.5
NYHA functional classification		
NYHA I		9.6
NYHA II		84
NYHA III		6.4
NYHA IV		0

Table III. Sub-clinical characteristics of the ASDs group.

Characteristics of ASDs group		Number	Percentage
Electrocardiogram	Normal sinus rhythm	69	73.4
	Supraventricular tachycardia	1	1.1
	Atrial fibrillation/flutter	2	2.1
	First-degree Atrioventricular Block	3	3.2
	Second-degree Atrioventricular Block	1	1.1
	Sinus tachycardia	10	10.6
	Atrial extrasystole	2	2.1
	Ventricular extrasystole	6	6.4
	Complete the Right bundle branch block (RBBB)	10	10.6
	Incomplete Right bundle branch block (RBBB)	52	55.3
Chest X-ray	Cardiomegaly	64	68.1
	Enlarged pulmonary artery arch	65	69.1
	Increased pulmonary circulation	67	71.3

decrease. FAC (Fractional Area Change) and ET increase. IVCT and IVRT decrease. RV Tei index gradually decreased after each examination. In 6 months after ASD closure, the right ventricular diameter and pulmonary trunk of patients in the case group decreased. These parameters of patients in the control group were higher, and FAC increased. IVCT, IVRT, ET, and RV Tei index decreased not statistically significantly compared to the control group.

Table VI shows changes in morphology and function of the left ventricle before and after ASD closure. After the device closure of ASD, the left ventricular diameter gradually increased. One week after ASD closure, EF% slightly increased but was not statistically significant. Three months after ASD closure, EF% significantly increased compared to one month after ASD closure.. IVCT, IVRT, and LV Tei index decreased, and ET increased statistically considerably compared to the previous examination. The left ventricular diameter of patients in the case group increased, and this parameter of patients in the control group was significantly higher. The LV Tei index of patients in the case group was significantly higher ($p < 0.05$).

Table VII shows the changes in some characteristics after six months of ASD closure. After six months from ASD closure, the proportion of patients with NYHA I was 90.3%, and there was no patient with NYHA IV.

Changes in Ventricular Septal Mobility and Tricuspid Valve Regurgitation After ASD Closure

After six months from ASD closure, the proportions of patients with abnormal ventricular sep-

Table IV. Parameters to evaluate pulmonary hemodynamics and circulation.

Characteristic		ASD group (n = 94)		Control group (n = 83)		*p*-value
		N	%	N	%	
Type of ASDs	ASD with one shunt	89	95.7			
	ASD with two shunts	3	3.2			
	TLN with > two shunts	1	1.1			
SPAP (mmHg)	Normal	3	3.2	83	100.0	< 0.001
	Slight increase	23	24.5	0	0.0	
	Moderate increase	59	62.8	0	0.0	
	Severe increase	9	9.6	0	0.0	
	$\bar{x} \pm$ SD	34.25 ± 8.12		25.5 ± 3.5		< 0.001
PVRI (Wood unit)	< 1.8	49 (+8)		69	83.1	< 0.001
	1.8-7	37	39.3	14	16.9	
	$\bar{x} \pm$ SD	1.89 ± 0.81		1.55 ± 0.18		< 0.001
Qp/Qs	$\bar{x} \pm$ SD	3.1 ± 1.3		1.1 ± 0.2		< 0.001

Table V. Changes in morphology and function of the right ventricle in 1 week, 1 month, and 3 months after ASD closure (n = 70).

Parameters	Before ASD closure (1)	After ASD closure (2)				Control group (3)	*p*-value (2-1)	*p*-value (2-3)
		1 week	1 month	3 months	6 months			
Right ventricular diameter (mm)	31.6 ± 5.0	26.9 ± 4.4*	25.3 ± 3.5*	24.4 ± 3.2*	23.7 ± 2.9	17.7 ± 2.5	< 0.001	< 0.001
Pulmonary trunk (mm)	31.1 ± 5.0	28.2 ± 5.1*	26.7 ± 3.8*	25.9 ± 3.7*	25.2 ± 3.6	21.1 ± 2.3	< 0.001	< 0.001
FAC (%)	47.4 ± 11.4	52.6 ± 9.1*	55.2 ± 7.5*	57.6 ± 6.5*	59.2 ± 5.4	58.8 ± 6.9	< 0.001	> 0.05
IVCT (ms)	26.3 ± 15.2	23.6 ± 11.8*	21.6 ± 10.7*	20.1 ± 9.2*	18.8 ± 8.2	18.5 ± 9.2	< 0.001	> 0.05
IVRT (ms)	58.1 ± 31.5	52.4 ± 24.8*	48.9 ± 23.5*	45.3 ± 22.0*	44.3 ± 20.9	36.1 ± 20.9	< 0.001	< 0.001
ET (ms)	288.6 ± 30.5	292.2 ± 27.0*	295.8 ± 27.4	297.1 ± 40.7	301.4 ± 26.6	303.8 ± 28.8	< 0.001	> 0.05
RV Tei	0.31 ± 0.21	0.27 ± 0.14*	0.26 ± 0.12	0.25 ± 0.11	0.23 ± 0.11	0.18 ± 0.10	< 0.001	< 0.001

*p-value < 0.001 in comparison with the previous examination.

Table VI. Changes in morphology and function of the right ventricle in 1 week, 1 month, and 3 months after ASD closure (n = 70).

Parameters	Before ASD closure (1)	After ASD closure (2)				Control group (3)	*p*-value (2-1)	*p*-value (2-3)
		1 week	1 month	3 months	6 months (2)			
Dd (mm)	39.7 ± 4.3	41.9 ± 3.8*	44.4 ± 2.6*	45.1 ± 1.8*	45.9 ± 1.4	46.9 ± 3.5	< 0.001	< 0.05
EF%	67.6 ± 7.2	69.3 ± 5.9	69.7 ± 5.5	70.5 ± 5.0**	70.5 ± 4.9	68.4 ± 5.1	< 0.05	< 0.05
IVCT (ms)	28.3 ± 16.8	26.2 ± 13.8*	24.1 ± 12.2*	22.5 ± 11.0*	21.5 ± 9.7	24.5 ± 13.1	< 0.001	< 0.05
IVRT (ms)	77.6 ± 21.4	72.0 ± 17.5*	67.4 ± 16.4*	63.5 ± 16.7*	60.4 ± 16.1	56.5 ± 18.5	< 0.001	< 0.05
ET (ms)	277.8 ± 23.1	283.3 ± 23.8*	287.5 ± 24.3*	291.9 ± 26.1*	294.4 ± 27.4	293.1 ± 28.2	< 0.001	> 0.05
LV Tei	0.38 ± 0.12	0.35 ± 0.09*	0.32 ± 0.09*	0.31 ± 0.09*	0.30 ± 0.08	0.28 ± 0.09	< 0.001	< 0.05

**p-value < 0,05; *p-value < 0,001 compared with the previous examination.

Table VII. Improve exercise capacity of patients after ASD closure.

Characteristics		Before ASD closure	After ASD closure six months	*p*-value
NYHA	I	5 (6.9)	65 (90.3)	< 0.001
	II	61 (84.4)	7 (9.7)	
	III	6 (8.3)	0 (0.0)	
	IV	0 (0.0)	0 (0.0)	
Ventricular septal mobility	Normal	60 (83.3)	72 (100.0)	< 0.001
	Abnormal	12 (16.7)	0 (0.0)	
Tricuspid valve regurgitation	Normal	0 (0.0)	0 (0.0)	< 0.05
	Mild	52 (72.2)	69 (95.8)	
	Moderate	14 (19.4)	3 (4.2)	
	Severe	6 (8.4)	0 (0.0)	
Pulmonary arterial hypertension	Normal	(4.2)	(84.7)	< 0.001
	Mild	(18.1)	(12.5)	
	Moderate	(65.3)	(2.8)	
	Severe	(12.5)	(0)	

tal mobility decreased in both groups. After ASD closure, the proportions of patients with moderate and severe tricuspid valve regurgitation decreased statistically significantly ($p < 0.001$ and $p < 0.05$, respectively). Distribution of degree of increase in pulmonary artery pressure before and after six months from ASD closure (n = 72). After six months from ASD closure, the proportion of patients with normal pulmonary artery pressure was 84.7%.

Change of Pulmonary Vascular Resistance after ASD Closure

In both groups, after ASD closure, pulmonary vascular resistance gradually decreased. In both groups, Figure 2 showed the change in Qp/Qs after ASD closure, with Qp/Qs dramatically reducing right after ASD closure. Then this rate gradually decreased to almost equal to the rate in the control group. Figure 3 shows the change of pulmonary vascular resistance after ASD closure. The resistance in the ASD group was higher than in the control group.

Discussion

General Characteristics

Females had a higher prevalence of ASD than males, which indicates illness etiology. The mean age of the disease group was 38, which appears

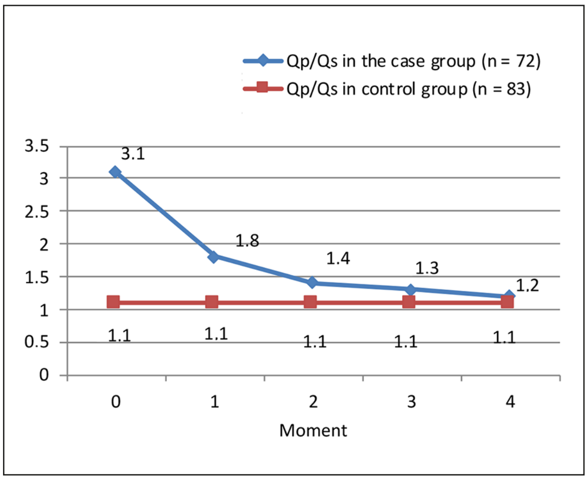

Figure 2. Change in Qp/Qs after ASD closure. 0: Before ASD closure; 1: right after ASD closure; 2: after 1 month from ASD closure; 3: after 3 months from ASD closure; 4: after 6 months from ASD closure. Qp/Qs in the control group were measured only at the moment 0.

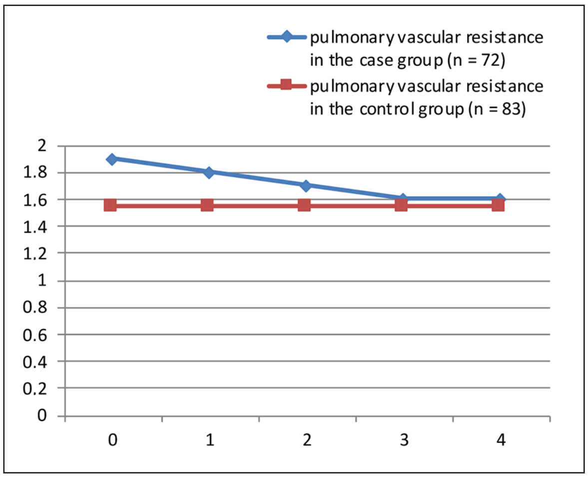

Figure 3. Change of pulmonary vascular resistance after ASD closure. 0: Before ASD closure; 1: right after ASD closure; 2: after 1 month from ASD closure; 3: after 3 months from ASD closure; 4: after 6 months from ASD closure. Qp/Qs in the control group was measured only at moment 0.

to be high, given that congenital heart disease can now be detected in children using modern technology. This is understandable in developing nations such as Vietnam, where routine screening is limited. Due to the onset of complications in the late stages of life, individuals might consider consulting a physician[15]. In our study, 47.8% of participants were over 40. The most common clinical symptoms were dyspnea, chest pain, and palpitations. NYHA II and III had an 84%. A systolic murmur was present in 85.1% of patients with ASDs. ASD is a clinical condition caused by the presence of one or more channels through the atrial septal wall – a fault in fetal development. While patient tolerance is rather good during the first two decades, ASD significantly influences the heart and pulmonary circulation by the third decade, necessitating early treatment of blocked vents, as restricting shunt currents is the source of hemodynamic problems. Subclinical features were more prevalent, as evidenced by right bundle branch block on echocardiography and symptoms of pulmonary arterial hypertension on chest X-ray.

Morphological and Function of Left and Right Ventricle

Dd and Ds were substantially smaller in ASD patients than in the control group (p-value < 0.05). Although the pulmonary output rose due to left-right shunts *via* ASD, the left ventricle's ability to relax was reduced. As a result, the preload on the left ventricle is decreased, and blood stagnates in the pulmonary vascular system. There was no difference in LV function between the ASD and control groups, as indicated by the absence of a statistically significant difference in EF% before closure between the control and ASD groups. This suggests that right chamber hypertension does not affect the LV's ability to contract. LV Tei index is much more significant in the ASD group than in the control group. According to Kim et al[16], the Tei index for the ASD group with a high PAP is substantially higher than the Tei index for the ASD group without a high PAP and the standard group, respectively, with $p < 0.001$.

The Tei index demonstrated a modest positive connection with the RV Tei index, PAP, PVR, and RV/LV rate in ASD patients. Increased PVR occurs due to changes in the pulmonary vascular anatomy caused by various factors. This process increases PAP, although an increase in PAP can also increase PVR. As a result, PVR has no direct effect on LV function. Kim et al[16] discovered a favorable association between the Tei index of ASD and systolic pressure in the RV chamber in research with a smaller sample size (47 individuals). Thus, increased PAP immediately results in RV dysfunction and LV function abnormality, as measured by diastolic function. While an increase in EF% is expected, in patients with PAP, LV function is compromised by the rise in contractile volume duration and a decrease in ejection duration. Reduced RV preload decreases RVDd, while decreased RV pressure decreases the influence on LV. Additionally, when the left-right shunt was closed, the LV preload increased, increasing LVD. This finding is consistent with study of Santoro et al[17]. Yuan et al[18] followed 61 patients with secundum ASD. The data indicated that LVDd increased following ASD closure. After a year, the size of the imagery returned to normal. There was no difference in LVDd one year or five years after the ASD was closed. There was no significant difference in ejection fraction before and after ASD closure. Six months after closure, the patient group's mean EF was identical to the control group.

Changes in the right ventricle's morphology and function, such as right ventricular diameter (mm), pulmonary trunk (mm), FAC (%), IVCT (ms), and IVRT (ms), were statistically significant after one week, one month, three months, and six months following closure. This was consistent with the mechanism of the left ventricle, as described previously. As volume contraction and contraction diminish, the ejection time increases during ASD closure, resulting in a shift in the Tei index. When we compared the Tei index across follow-ups, we saw that it declined dramatically. However, six months after the ASD was closed, the average value remained considerably greater than the control group. Thus, following ASD closure, ventricles gradually regained their normal form and function, where the systolic function recovered more quickly. The diastolic function is also gradually, but more slowly, restored. The time required for volume expansion was still more significant in the ASD group than in the control group.

Changes in Exercise Capacity and Hemodynamics

After six months of transcatheter percutaneous closure, NYHA considerably improved in our study. This conclusion is consistent with previous research[1,20] in terms of long-term outcome (12 years)[1] and intermediate-term effect (24 hours)[20].

A return to normal followed the mild-moderate increase in pulmonary arterial pressure. The mobility of the ventricular septum had returned to normal. It aided in the enhancement of exercise capacity. This could be because exercise capacity changes when VO2max improves following closure[21]. The Qp/Qs ratio was measured using Doppler echocardiography, which revealed that it decreased significantly upon closure and remained statistically significant six months later. Another investigation[21] confirmed these findings. At six months following the closure, pulmonary vascular resistance, a critical criterion for determining closure, remained statistically significant, but steadily declined. The rate of change was slow due to changes in the pulmonary vascular anatomy.

Conclusions

Percutaneous transcatheter closure in Vietnamese adult atrial septal defect was an effective technique. Ventricle morphological and hemodynamic abnormalities following closure recovered statistical significance over time, particularly in the left ventricle.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval

The Vietnam Military Medical University Ethics Committee approved the study and authorized its conduct and follow-up. The study was in line with the Declaration of Helsinki.

Informed Consent

Individual patient consent for inclusion in the study was obtained. Before the operation, written informed consent was provided from all participants after a thorough explanation of the purpose of this study. Patients had the right to discontinue at any time during the study.

Authors' Contribution

All authors made substantial contributions to conceptualization and design, data acquisition, data analysis, and interpretation, took part in the drafting of the initial manuscript and revising it critically, gave final approval of the version to be published, agreed to submit to the current journal, and agreed to be accountable for all aspects of the work.

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