Outcomes of Venus P-valve for dysfunctional right ventricular outflow tracts from Indian Venus P-valve database

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ABSTRACT

Background : **Balloon-expandable pulmonary valves are usually not suitable for dilated native outflow tracts.**

Methods : **Indian Venus P-valve registry was retrospectively analyzed for efficacy, complications, and midterm outcomes. Straight valve was used in prestented conduits in patients with right ventricular pressure above two-thirds systemic pressure and/or right ventricular dysfunction. Flared valve 1–4 mm larger than balloon waist was used in native outflow in symptomatic patients, large ventricular volumes, and ventricular dysfunction.**

Objectives : **A self-expanding porcine pericardial Venus P-valve is available in straight and flared designs..**

Results : **Twenty-nine patients were included. Straight valve was successful in all seven conduits, reducing gradients significantly, including one patient with left pulmonary artery (LPA) stent. Flared valve was successfully implanted in 20 out of 22 native outflow tracts. Sharp edges of the older design contributed to two failures. Complications included two migrations with one needing surgery, endocarditis in one, insignificant wire-frame fractures in three, and groin vascular complication in one patient. There were no deaths or valve-related reinterventions at a mean follow-up of 47.8 ± 24.5 months (1–85 months). Modifications of technique succeeded in three patients with narrow LPA. There was significant improvement in symptoms, right ventricular volume, and pulmonary regurgitant fraction.**

Conclusion : **Straight and flared Venus P-valves are safe and effective in appropriate outflow tracts. Straight valve is an alternative to balloon-expandable valves in stenosed conduits. Flared valve is suitable for large outflows up to 34 mm, including patients with LPA stenosis. Recent design modifications may correct previous technical failures. Studies should focus on durability and late complications.**

Keywords : Balloon sizing, infective endocarditis, left pulmonary artery stenosis, percutaneous pulmonary valve implantation, self-expanding valve, valve migration

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INTRODUCTION

Surgical reconstruction of right ventricular outflow tracts (RVOTs) using patches or conduits is an integral part of management of various congenital heart diseases. In 85% of patients, reconstruction involves a transannular patch and in 15% of patients, may involve a conduit.[1] Percutaneous valves are an alternative to surgery for narrowing or regurgitation of the outflow tracts when these patients need a pulmonary valve replacement.[2,3] Melody valve (Medtronic Inc., Minneapolis, MN) has limited utility in native outflow tracts.[4] Outflows with transannular patches have varied morphology and need a different approach.[5] Various valve designs have been evaluated to address this unmet need.[6-8] The SAPIEN valve (Edwards Lifesciences, Irvine, CA) has the potential for use in native outflow tracts up to 29 mm.[9]

The Venus P-valve (Venus Medtech, Hangzhou, PRC) is available in two designs. The straight design is used in prestented conduits.[10] The flared design addresses the majority of native outflow tracts with transannular patches.[11-13] The initial experience has been encouraging for both designs.[10-17] Reports from China, South America, Thailand, and Europe describe patients implanted with Venus P-valve.[10-17] The device still awaits approval for clinical use from the regulatory bodies.

We present the procedural details and midterm follow-up of patients in the Indian registry, who underwent percutaneous pulmonary valve implantation (PPVI) with these two designs of Venus P-valve in the past 6 years.

METHODS

This multicenter retrospective observational study evaluated patients who underwent Venus P-valve implantation after obtaining approval for compassionate use from the Indian regulatory body. Indian registry, involving seven institutions, aimed to analyze the safety, efficacy of the procedure and to study the midterm outcome and complications. Ethical committees of all the participating institutions approved the study. Fully informed written consent was obtained from all the patients for the procedure and anonymized reporting of the results. Institutional review boards that included pediatric cardiac surgeons at all participating institutions reviewed each patient details before the procedure.

Initial evaluation

Echocardiography evaluated patients with significant RVOT regurgitation or stenosis. In patients with stenosis, a multislice computed tomography analyzed the diameter and length of the stenotic lumen, extent of circumferential calcification, and relationship to the coronary arteries. In regurgitant outflows, cardiac magnetic resonance imaging (CMR) analyzed the regurgitant fraction, ventricular volumes, and their function. The indication for PPVI was based on standard guidelines.[18-20]

Stenotic outflow tracts

Echocardiography identified features of systemic venous congestion, right ventricular dysfunction, secondary tricuspid regurgitation, outflow gradients, hilar pulmonary arteries, and other residual lesions. Patients with symptomatic worsening unexplained by other reasons, right ventricular systolic pressures more than two-thirds of systemic pressures, and right ventricular systolic dysfunction underwent stent angioplasty to relieve the obstruction before a straight Venus P-valve implantation.

Stent angioplasty for stenotic outflow

Proximity of conduits to coronary arteries was predicted by computed tomography. After excluding very dense circumferential calcification and patients at risk of coronary occlusion, the remaining patients underwent serial dilatations starting with Mustang Balloons (Boston Scientific, Marlborough, MA) up to 12 mm and later Atlas Gold Balloons (Bard Peripheral Vascular, Tempe, AZ) beyond 14 mm with 2 mm serial increments, under careful angiographic monitoring. After dilating the conduit to more than 80% of its original diameter, selective coronary angiograms were performed during full inflation of the final balloon to exclude interference with coronary flows. Circumferentially calcified conduits were stented with covered cheatham-platinum (CP) (Numed Inc., Hopkinton, NY) or covered AndraStent XXL (Andramed, Reutlingen, Germany) stents. If calcification was noncircumferential, stenting was performed using Palmaz XL (Cordis endovascular, Santa Clara, CA), LD Max (ev3 endovascular Inc., Plymouth, MN), CP or AndraStent XXL stents. Stent recoil was reinforced using one or two additional stents until pressure gradients dropped below 20 mmHg.

Regurgitant dilated outflows

Symptomatic patients and those who met CMR and electrocardiographic criteria for indication for PPVI underwent balloon interrogation before flared Venus P-valve implantation.[5] Outflow tracts larger than 34 mm and pyramidal-shaped Type I outflow tracts were excluded.[5] Lesions warranting corrective surgery, such as resection of RVOT aneurysms, closure of large residual defects, repair or replacement of severely regurgitant tricuspid valves were also excluded. Patients with severe unilateral pulmonary artery stenosis that precluded surgical or interventional rehabilitation were included, provided the outflow anatomy was suitable for Venus P-valve.

Balloon interrogation

The differences between the RVOT dimensions on CMR and balloon interrogation made the latter a mandatory

step.[11-17] After placing a stiff Lunderquist guidewire (Cook medical, Bloomington, IN) to straighten the outflow tract, marker pigtail angiograms were performed in orthogonal projections to measure the RVOT dimensions. Once the hemodynamics was recorded, a long compliant AGA sizing balloon (Abbott, Plymouth, MN) was inflated across the outflow until a right ventriculogram confirmed complete occlusion. Selective coronary angiography during full balloon inflation assessed the risk of compression. The waist was measured after calibration with the marker pigtail placed alongside the sizing balloon. Venus P-valves were customized 2–4 mm larger than the interrogating balloon waist. Patients with balloon waist above 34 mm were excluded.

Venus P-valve

Venus P-valve comprised of a self-expandable nitinol framework with a trileaflet porcine pericardial valve, available in straight and flared designs.[10,17] Both the designs were available in diameters of 18–36 mm in 2 mm increments. The flared design of the valve went through three modifications from its first design. The first modular design with three sutured components was changed to a unibody with a thin pericardial lining for the struts of the distal flare. In the third design, this thin pericardial lining was removed from the six open cells in the distal flare.[11-14] The fourth design since 2018 had five open cells in distal flare that connected all the sharp edges to the outer wire frame [Figure 1]. The valve was rinsed to remove the glutaraldehyde preservative and crimped in ice-cold saline to reduce the nitinol memory, using a proprietary compression device and loaded on the delivery system.

Implantation procedure

The procedure was performed under general anesthesia. Two femoral venous and one arterial accesses were used. In patients with occluded iliac veins on one side, a right internal jugular venous access was used for the marker pigtail angiographic catheter. The valve delivery system was advanced toward the RVOT over a Lunderquist wire parked deep in left pulmonary artery (LPA). The distal flare was exposed in the proximal LPA. The remaining constrained valve was progressively exposed under guidance from repeated right ventriculograms in such a way that the proximal marker coincided with the proximal waist. If an initial attempt from LPA failed, the valve was deployed from right pulmonary artery. When the large profile rigid delivery system failed to advance through a sharp angulated RVOT, a 12–16 mm balloon was inflated in the distal outflow through the second venous access to displace the advancing valve away from the lateral walls of the outflow. A 65 cm long 26F braided sheath, when available, was placed across the outflow to facilitate passage of the delivery system to the desired site.[21] After deployment, right ventricular and pulmonary artery angiogram were performed to assess valve position, competence, and adequacy of flow through the branch pulmonary arteries. Hemostasis was achieved by figure-of-8 suture and manual compression.

Follow-up

Periprocedural antibiotics and low-molecular-weight heparin were continued for 3 days, and patients were discharged on dual antiplatelet therapy that was continued indefinitely. Antibiotic prophylaxis was administered for all major dental and urogenital surgical procedures. Clinical evaluation combined with electrocardiogram, fluoroscopy, and echocardiogram was performed at 1 and 3 months after the procedure and 6 monthly thereafter. In patients who did not receive any ferromagnetic stents, CMR was performed after 6 months.

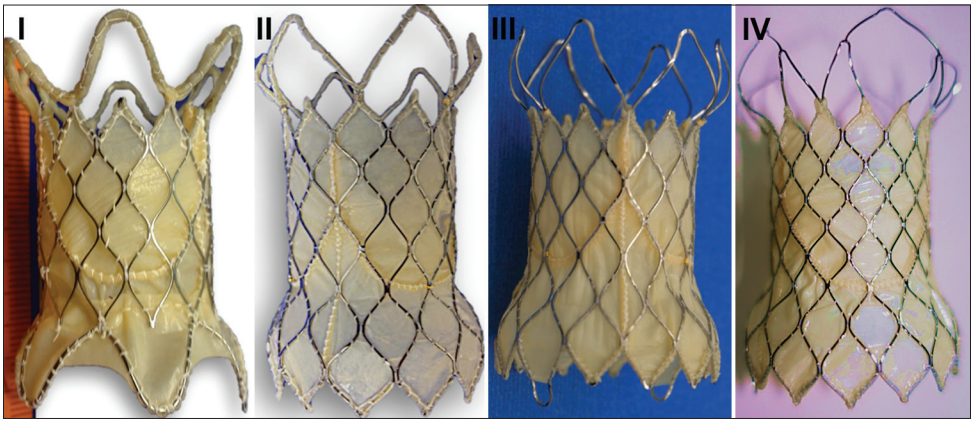

Figure 1: Venus P, a trileaflet porcine pericardial valve on a self-expanding nitinol frame, went through three modifications. The initial modular design (I) consisting of separate midvalve segment connected to proximal and distal flare changed to unibody design (II) on a single nitinol frame. Thin porcine pericardial strips that lined the six open cells of distal flare were removed in the third (III) design. The recent design (IV) connected the sharp edges through nitinol wires to the five open cells in the distal flare. The midvalve segment of the first-generation modular design without the flares on either side formed the straight design valve

Statistical analysis

Data were entered in Microsoft Excel and analyzed using SPSS version 23 (IBM Corp, Armonk, NY). The distribution of categorical data was expressed as frequency and percentage. The continuous variables were expressed as mean with standard deviation or median with range. The comparison of the continuous variables was carried out by independent Student's *t*-test or one-way analysis of variance whichever was appropriate based on the distribution of data and number of groups. All statistical analysis was carried out at 5% level of significance and $P < 0.05$ was considered as significant.

RESULTS

Patient population

A total of 35 patients were evaluated with balloon interrogation in the cardiac catheterization laboratory [Figure 2]. Twenty-nine patients selected after balloon interrogation from seven institutions were included for Venus P-valve implantation from March 2014 after excluding 6 patients [Table 1]. The measurements on CMR, catheter angiography, and balloon interrogation influenced the indication and selection of the valve [Table 2]. Seven patients with circumferential conduits, who received straight Venus P-valve, formed Group A [Tables 3 and 4] and 22 patients with native outflow tracts reconstructed with transannular patches underwent implantation of flared Venus P-valve and formed Group B [Tables 5 and 6].

Patient inclusion

The conduit stenosis was severe causing elevation of right ventricular pressures to more than two-thirds of systemic pressures in six patients in Group A. One patient in heart failure with right ventricular ejection fraction of 23% had a conduit gradient of 38 mmHg and was included. Two patients in Group B had indexed right ventricular end-diastolic volume <150 ml. While one of these had right ventricular ejection fraction <47%, the other was symptomatic without any other explanations. Among the four included patients with LPA stenosis, one was treated by stent angioplasty and the others had poor left lung

Table 1: Patient clinical details

Parameters	Values
Number of patients	29
Group A: Circumferential conduits	7
Group B: Native outflow with transannular patch	22
Age	25.48±11.72 years (12-61 years)
Weight	59.9±13.7 kg (39-86 kg)
Male:female	20:09
Age at primary corrective surgery (years), range	8.82±8.5 (1-30)
Time from primary surgery to PPVI (years), median (range)	16.3±7.8, 15 (3-45)
Number of surgeries before PPVI	
1	19
2	8
3	1
Group A - Primary diagnosis	7 patients
TOF with PA	4/7
Ross surgery for aortic valve disease	2/7
Transposition of great arteries VSD PS	1/7
Group B - Primary diagnosis	22 patients
TOF transannular patch	18/22
Double outlet RV transannular patch	2/22
Infundibular and valvar pulmonary stenosis	1/22
Pulmonary band for VSD	1/22
NYHA class	
I	8
II	19
III	1
IV	1
Arrhythmias	
None	28
Chronic atrial fibrillation	1
QRS duration on electrocardiogram	152.14±28.2 ms (80-220)
QRS duration>140 (ms)	18/29
QRS duration>160 (ms)	7/29
Hemodynamic lesion	
Predominant pulmonary stenosis	5/29
Isolated pulmonary regurgitation	21/29
Combined stenosis and regurgitation	3/29

PPVI: Percutaneous pulmonary valve implantation, VSD: Ventricular septal defect, PS: Pulmonary stenosis; NYHA: New York Heart Association, TOF: Tetralogy of Fallot, PA: Pulmonary atresia, RV: Right ventricle

Table 2: Cardiac magnetic resonance imaging and angiography*

Parameters	Mean values
Group A	
Right ventricular outflow dimension by magnetic resonance (mm)	19.3±1.2 (18-20)
Right ventricular outflow dimension by angiography (mm)	21.1±1.2 (19-23)
Right ventricular outflow dimension by balloon sizing (mm)	20.9±1.7 (19-24)
Mean difference (angiography vs. balloon) (mm)	0.3±0.8 (−1-+1)
Mean difference (magnetic resonance vs. balloon) (mm)	0±1.7 (−2-1)
LPA stenosis or hypoplasia	1/7
Group B	
Pulmonary regurgitant fraction (%)	45.6±11.8 (26-64)
Indexed right ventricular end-diastolic volume (ml)	167.26±25.9 (120-230)
Right ventricular ejection fraction (%)	46.9±9.6 (27-65)
Right ventricular outflow dimension by magnetic resonance (mm)	25.1±4.2 (19-32)
Right ventricular outflow dimension by angiography (mm)	26.1±3.3 (20-32)
Right ventricular outflow dimension by balloon sizing (mm)	28.0±3.3 (23-33)
Mean difference (angiography vs. balloon) (mm)	1.9±2.4 (−8-+2)
Mean difference (magnetic resonance vs. balloon) (mm)	2.8±2.9 (−10-+1)
LPA stenosis or hypoplasia	4/22

*Values expressed in mean±SD (range). SD: Standard deviation, LPA: Left pulmonary artery

Table 3: Group A patients individual clinical details

Number	Age (years)/ sex	Weight (kg)/ height (cm)	Diagnosis and surgery	Number of cardiac surgeries	Age at first surgery	Age at last surgery	Hemodynamics	PS grad echo/ cath (mmHg)	Stent used	Poststent PS grad (mmHg)	RV EDV (ml)	PRF (%)	RV EF (%)
1	12/ female	42/161	TOF PA xenograft conduit	1	7	7	Stenosis	96/76	LDMax 36 mm P4014	15			
2	29/male	64/184	TOF PA homograft Conduit revision	2	14	16	Mixed	40/38	P5014	10	184	30	23
3	24/ female	77/163	Ross procedure homograft	1	12	12	Stenosis	106/100	P4014	10			
4	37/ female	48/163	TOF PA homograft	1	20	20	Mixed	96/79	CP 26 mm LPA CP 16 mm	6	66	39	73
5	24/ female	42/150	TOF PA homograft conduit revision	3	5	11	Stenosis	74/62	CCP 45 mm Andra XXL 43 mm	12	117	17	40
6	34/male	79/171	Ross procedure homograft	1	21	21	Stenosis	76/74	Andra XL 30 mm Andra XL 39 mm	20			
7	24/male	86/176	Rastelli DTGA VSD PS conduit revision	2	6	11	Stenosis	84/95	Andra XL 57 mm Andra XL 57 mm P4014	0			

PS: Pulmonary stenosis, Echo: Echocardiography, Cath: Catheterization, Grad: Gradient, RVEDVI: Right ventricular end-diastolic volume index, PRF: Pulmonary regurgitant fraction, RVEF: Right ventricular ejection fraction, TOF: Tetralogy of Fallot, PA: Pulmonary atresia, CP: Cheatham platinum, LPA: Left pulmonary artery, CCP: Covered CP, DTGA: d-transposition of great arteries, VSD: Ventricular septal defect

arborization. One patient with a residual ventricular septal defect underwent device closure 3 months after valve implantation.

Prestenting of narrowed conduits

Prestenting in seven patients with narrowed conduits in Group A reduced the mean outflow gradient from 74.9 ± 20.7 mmHg (38–100 mmHg) to 12.29 ± 6.87 mmHg (0–20 mmHg). A single stent was used in three patients, two stents in three, and three stents in one patient [Table 3]. The covered stent was used in one patient with dense circumferential conduit calcification, while the others received bare stents. The median duration from prestenting to PPVI was 11 weeks, ranging from 2 to 208 weeks.

Procedural success

Valve implantation was successful in 27 (93%) patients. Seven cases (Group A) received straight Venus P-valve and 20 (Group B) received flared Venus P-valve. Two

Table 4: Group A patients individual hemodynamics and follow-up

Number	RA (mmHg)	RV (mmHg)	PA (mmHg) systolic/ diastolic/ mean	Waist CMR/ angio/ balloon (mm)	Valve size*	Additional procedural features	Immediate postvalve gradient (mmHg)	Years after last surgery	Weeks after stent	PR severity	Valve gradient (mmHg)	Follow-up (months)
1	13	35	30/11/18	-/21/21	22-35	Two stents	6	5	6	0	23	85
2	11	66	46/11/26	21/21/20	22-35	Noncircumferential calcification	13	13	2	0	22	74
3	11	47	35/18/26	-/21/20	22-35	RPA deployment; balloon assistance	18	12	208	I	35	74
4	12	68	40/14/22	18/21/20	22-35	Post-LPA stent	11	17	35	0	18	74
5	15	40	33/10/21	20/19/19	22-30	Dense circumferential calcification	20	13	3	0	22	67
6	19	66	44/14/29	-/22/22	22-30	Two stents	1	14	11	I	30	57
7	10	41	30/6/18	-/23/24	24-30	Three stents	17	13	22	I	18	42

*Diameter-length (mm). RA: Right atrium, RV: Right ventricle, PA: Pulmonary artery, CMR: Cardiac magnetic resonance imaging, PR: Pulmonary regurgitation, RPA: Right pulmonary artery, LPA: Left pulmonary artery

Table 5: Group B patient clinical details

Number	Age/sex	Weight (kg)	Diagnosis	Number of cardiac surgeries	Age at first surgery (years)	Predominant pathology	NYHA class	Branch PA	QRS duration (ms)	RVEDVI (ml)	PRF (%)	RVEF (%)
1	19/male	45	TOF TAP	2	4	Regurgitation	II		140	153	40	62
2	15/male	66	DORV TAP	1	1	Regurgitation	II	LPA stenosis	170	120	30	60
3	41/male	71	TOF TAP	1	11	Regurgitation	I		220	190	63	27
4	23/female	53	TOF TAP	1	2	Regurgitation	I		160	161	53	65
5	23/male	69	TOF TAP	2	1	Regurgitation	I		160	156	49	36
6	14/male	46	TOF TAP	1	1	Regurgitation	I		120	189	64	48
7	21/male	76	TOF TAP	2	18	Regurgitation	II		160	144	53	43
8	19/male	53	TOF TAP	2	2	Regurgitation	II		200	139	26	43
9	61/male	75	TOF TAP	1	16	Regurgitation	II		160	171	42	41
10	14/male	64	TOF TAP	1	1	Regurgitation	II	LPA stenosis	140	150	35	56
11	44/male	40	TOF TAP	2	22	Regurgitation	IV		170	230	36	50
12	21/female	59	TOF TAP	1	3	Regurgitation	II		120	159	52	46
13	18/male	39	TOF TAP	1	4	Regurgitation	I		170	151		46
14	17/male	70	PA band VSD	2	2	Regurgitation	I		140	161		35
15	33/male	75	TOF TAP	1	26	Regurgitation	II		160	150	30	53
16	17/male	75	TOF TAP	1	6	Regurgitation	II		160	195	54	40
17	16/male	40	TOF TAP	1	2	Regurgitation	II		150	172	60	43
18	15/male	58	TOF TAP	1	4	Regurgitation	I		160	196	40	47
19	49/male	60	DORV TAP	1	30	Moderate PS+regurgitation	II	LPA hypoplasia	160	166	39	46
20	20/female	58	TOF TAP	1	1	Regurgitation	II		140	191	48	50

NYHA: New York Heart Association, PA: Pulmonary artery, RVEDVI: Right ventricular end-diastolic volume index, PRF: Pulmonary regurgitant fraction, RVEF: Right ventricular ejection fraction, TOF: Tetralogy of Fallot, TAP: Transannular patch, DORV: Double outlet right ventricle, LPA: Left pulmonary artery, VSD: Ventricular septal defect

procedures with flared design failed as the sharp edges from the midsegment of the third generation valve pierced through the nylon sleeve capsule while manipulating the rigid delivery system through a sharply angulated RVOT. A safe uncomplicated withdrawal of the delivery system was followed later by elective surgery.

Procedural details

Three patients in Group B and one patient in Group A had LPA stenosis. The delivery system with nose cone could not be advanced into the LPA in one of these patients despite downsizing the valve from 30 mm to 28 mm. After inflating a balloon in distal outflow tract to reduce friction of the delivery system, the distal flare was opened in proximal LPA leading to successful deployment [Figure 3]. In one further patient with unobstructed LPA, similar difficulties were encountered needing deployment from the right pulmonary artery. Conduit stenosis associated with discrete LPA origin narrowing in a patient was stented using two separate bare CP stents. Five months later, a straight design Venus P-valve implantation was implanted uneventfully, as the nose cone of the short delivery system barely crossed the LPA stent. The recently introduced 65 cm long braided sheath placed across the RVOT to facilitate passage of the rigid valve delivery system was used in only one patient [Figure 4].

Procedural complications

A 32 mm flared Venus P-valve migrated proximally in a 17-year-old male causing severe tricuspid regurgitation. The valve was anchored surgically

Table 6: Group B patients hemodynamics and follow-up

Number	RA (mmHg)	RV (mmHg)	PA (mmHg) systolic/ diastolic/ mean	Waist CMR/ angio/ balloon (mm)	Valve size*	Years after surgery	Events	PR severity	Stent fracture	RV EDVI (ml)	PRF (%)	RVEF %	Follow-up (months)
1	7	29	24/4/14	27/28/28	34-30	15		Mild	Yes	99	0	54	67
2	7	45	35/2/14	22/26/26	28-30	15	RPA deployment balloon assist	Mild		88	1	50	56
3	7	33	35/5/16	32/31/33	36-30	31		No					18
4	8	22	22/5/15	19/25/23	32-25	21	Long 65 cm sheath used	No		107	4	49	18
5	7	43	32/5/15	29/29/32	36-30	21		No					24
6	5	40	30/5/14	30/30/30	36-30	14		Trivial	Yes				24
7	4	40	28/5/10	-/27/27	34-25	3		Trivial		89	8	49	24
8	6	40	30/5/15	22/23/24	30-25	17		No		131	3	41	30
9	18	60	57/15/32	23/23/23	30-30	45		Trivial		95	3	44	42
10	7	32	24/3/12	27/26/29	32-30	14	Moderate TR medical follow-up	Trivial					46
11	14	50	45/10/22	28/25/27	30-30	22	VSD device	No					46
12	8	40	40/10/20	32/32/32	36-30	17	Surgery for femoral AV fistula	Trivial	Yes				67
13	6	32	20/5/13	25/25/27	36-35	14		Trivial					57
14	18	45	44/20/28	19/23/23	28-25	15		Trivial					25
15	10	40	30/5/14	25/27/29	30-30	7		Trivial		110	5	51	84
16	7	40	34/4/12	23/28/33	32-30	12	Proximal shift Surgery	No					84
17	5	40	38/10/18	20/20/26	30-30	14		No		155	8	50	62
18	5	60	40/10/17	27/25/28	34-30	11		No					24
19	8	65	25/10/15	20/20/28	32-30	19	Balloon dilatation for PS	No					18
20	3	32	31/1/13	27/29/32	36-25	19		Trivial					1

*Diameter-length (mm). RA: Right atrium, RV: Right ventricle, PA: Pulmonary artery, CMR: Cardiac magnetic resonance imaging, PR: Pulmonary regurgitation, RVEDVI: Right ventricular end-diastolic volume index, PRF: Pulmonary regurgitant fraction, RVEF: Right ventricular ejection fraction, RPA: Right pulmonary artery, TR: Tricuspid regurgitation, AV: Arteriovenous, PS: Pulmonary stenosis

on cardiopulmonary bypass after opening the transannular patch and continued to function well after 6 years of follow-up. A similar less severe migration of another 32 mm flared valve in a 14-year-old male resulted in moderate tricuspid regurgitation that was conservatively followed for 3 years without any progression. A retrospective review of their CMR showed a mild pyramidal shape of the RVOT. Femoral arteriovenous fistula after removal of a 26F sheath used for deploying a 36 mm flared valve needed surgical repair in one patient.

Complications and reinterventions on follow-up

Followup data of all 27 patients were available. At a median follow-up of 46 months (1–85 months), there were no deaths or valve-related reinterventions. A residual ventricular septal defect was closed with a device 3 months after PPVI in one patient. There were no other reinterventions. Transient fever after procedure seen in early patients was prevented later by thorough prolonged rinsing of the valve to remove the preservative. One episode of culture-negative infective endocarditis at 4 years after implantation was successfully treated medically with no change in valve function. Valve wire-frame fracture was seen in 3 (11.4%) patients in Group B, noticed at 1, 12, and 24 months on fluoroscopy, and was confined to the proximal flare without compromising the valve function [Figure 5].

Follow-up assessment

One-year and 2-years follow-up were completed by 26 (96.3%) and 23 (85.2%) patients, respectively. Seven patients had trivial to mild clinically inaudible pulmonary regurgitation at their last follow-up. There was no paravalvular leak in any of the patients. A repeat CMR in eight patients showed significant reduction in right ventricular volume and regurgitant fraction [Table 7]. All Group B patients had valve gradients <20 mmHg on the last follow-up. The reduction in outflow gradients in conduits persisted on follow-up. All patients had a subjective improvement of symptoms and effort tolerance, but none underwent any cardiopulmonary exercise tests. Antiplatelets were not discontinued in any patient.

DISCUSSION

Utility of a functioning pulmonary valve

Many patients with reconstructed RVOT need pulmonary valve replacement in adolescence or adulthood.[19] Patient selection is guided by worsening symptoms along with

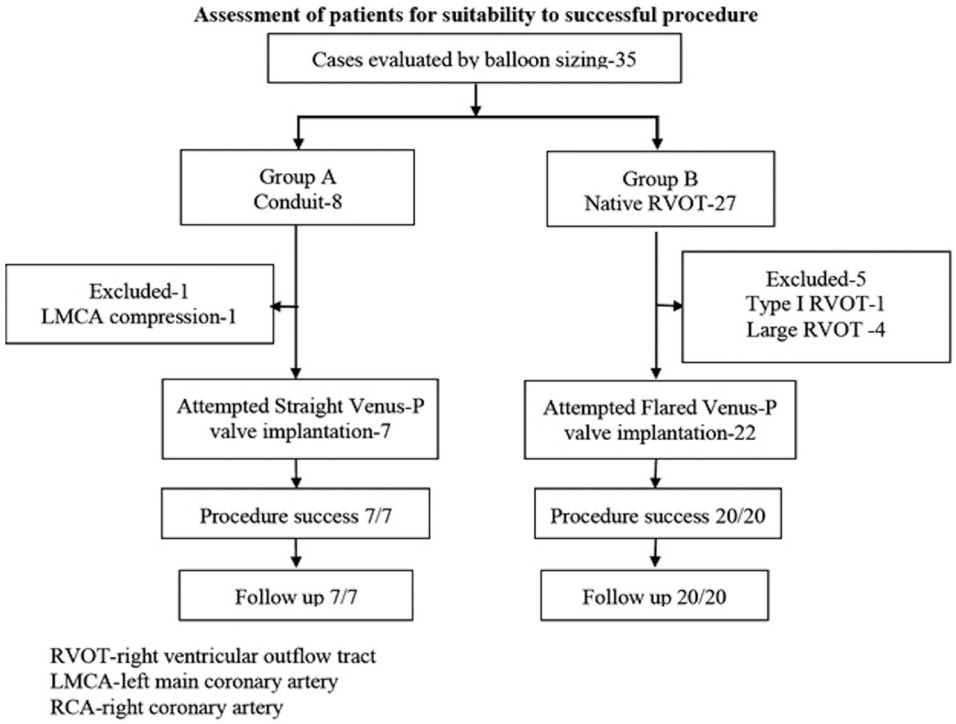

Figure 2: Flow chart of total patients assessed for percutaneous pulmonary valve implantation and procedural success

Table 7: Comparison of parameters before and after valve implantation

Parameter	Pre	Post	*P*
CMR in Group B patients			
RVEDVI (ml)	147.38±18.57	107.11±22.56	0.001
PRF (%)	37.25±14.33	4.11±2.76	<0.001
RVEF (%)	48.06±8.85	48.78±3.9	0.7
Hemodynamic PS gradient in Group A patients (mmHg)	74.86±20.74	12.29±6.87	<0.001

CMR: Cardiac magnetic resonance imaging, RVEDVI: Right ventricular end-diastolic volume index, PRF: Pulmonary regurgitant fraction, RVEF: Right ventricular ejection fraction, PS: Pulmonary stenosis

certain hemodynamic, CMR, and electrocardiographic indicators.[18] A consistent reduction in right ventricular volumes, improved left ventricular filling, and improved symptoms are observed after PPVI, although ejection fraction, exercise parameters, and arrhythmia burden are largely unchanged.[19] Stenosed conduits demonstrate reduction in gradients and improved symptoms after PPVI.[19] Chest adhesions, bleeding, cardiac ischemia, and multiorgan dysfunction favor percutaneous valves to surgery.[22] Lack of mortality and life-threatening complications in our group show safety of the percutaneous strategy.

Percutaneous options for dilated outflow tracts

Balloon-expandable valves cater for a minority with narrowed conduits or small outflow tracts. Despite the availability of SAPIEN valves up to 29 mm, two-thirds of RVOT are larger than 26–27 mm and may not be suitable for this valve.[4,9,23] The flared Venus P-valve is designed primarily to address these patients.[11-18] RVOT dimensions exceeded 28 mm in our group. None of the current valves except Venus P could have been considered for such large outflow tracts.[13]

Implantation success

PPVI was successful in 93% of cases. Two failures were related to the sharp edges of the older design that protruded through the nylon sleeve capsule of the delivery system while manipulating an angulated RVOT. They were removed uneventfully. The recent modification of design connected the sharp edges to the outer frame.[13] The present modification eliminated this problem despite using a large 36 mm valve in six subsequent patients. The Chinese Venus P study published the largest experience of 55 patients with 98.2% success, but the largest valve was 32 mm.[14] Procedural success was comparable to the United States Melody valve trial and Compassion trial.[24,25]

Comparison with other Venus P registries

Delayed referral and advanced hemodynamic derangements are common in developing countries due

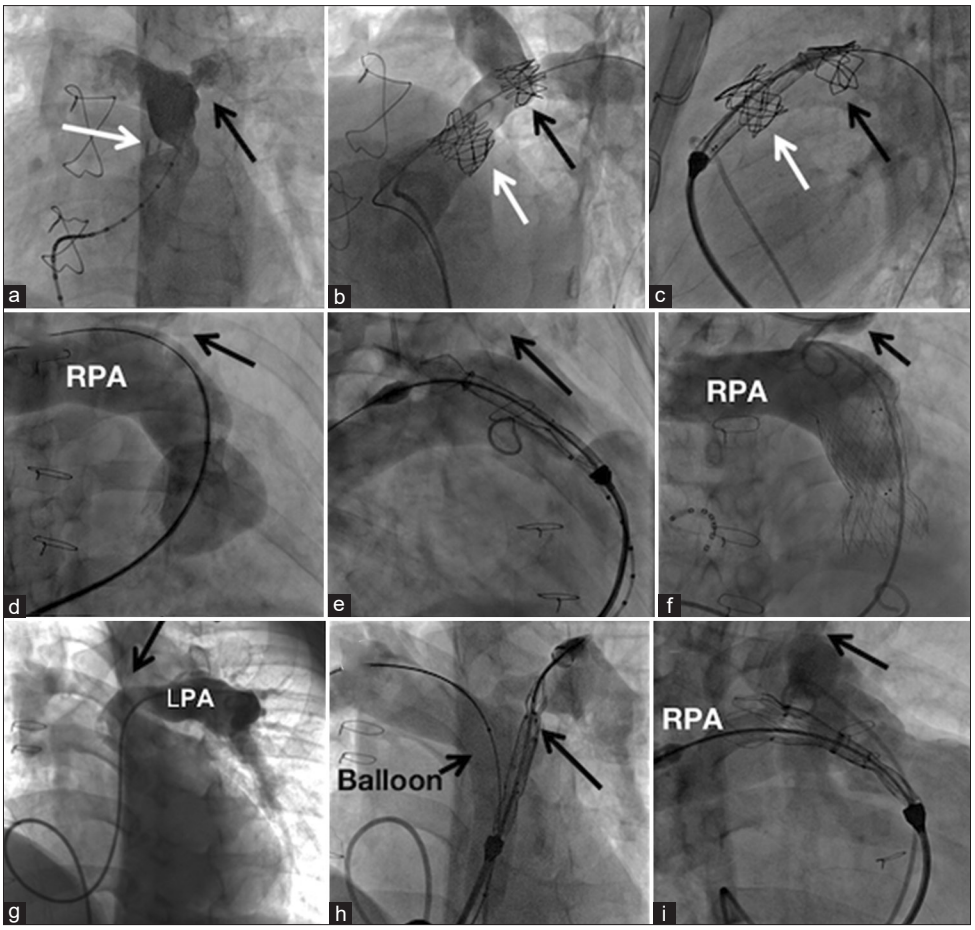

Figure 3: Valve implantation in the presence of left pulmonary artery stenosis. Severe conduit stenosis (white arrow) and left pulmonary artery stenosis (black arrow) seen in left anterior oblique projection (a) were stented (b) before a straight Venus P-valve implantation (c). The left pulmonary artery stent did not hinder the valve delivery system. Extreme hypoplasia of left pulmonary artery in the second patient with native outflow tract (d) forced a right pulmonary artery (RPA) deployment (e) of a flared Venus P-valve. (f) A sharp kink in left pulmonary artery (LPA) origin shown in left anterior oblique projection (g) in third patient was crossed by the delivery system of a flared Venus P-valve aided by a balloon in the outflow tract (h). A similar angulation in fourth patient would not permit the delivery system (i) and managed by a RPA deployment

to social and logistic reasons.[26] The right ventricular volumes in our patients were larger than patients reported in large Chinese, European, South American, and multicenter Venus P registries.[12,14,16,17] The larger balloon waist dimensions in this cohort compared with the other registries mandated valves larger than 28 mm in all the patients with native RVOT. Six out of the twenty patients needed the largest 36 mm valve. Inadequate right ventricular remodeling after delayed interventions should force early recognition and intervention.[27]

Valve deployment

The Venus P-valve is usually deployed from the LPA, which accommodates the distal flare of the valve.[17] A stented or stenotic LPA hindered this deployment and was excluded in two large registries.[14,17] In our series, LPA stenosis in three patients in Group B was managed with right pulmonary artery deployment in two and balloon-assisted deployment in one [Figure 2]. A stent deployed in the LPA in one Group A patient did not pose any problem as the nose cone of the straight valve delivery system did not protrude beyond the stent. Therefore, a narrow LPA need not be considered as an absolute contraindication for Venus P-valve.

Straight Venus P-valve in stented conduits

Complications

Valve migration in two patients was managed with surgical anchoring in one and conservatively in the other. The reasons for proximal migration may be technical due to non-release of the ear-loop or anatomical due to pyramidal RVOT.[14] Repeated angiographic monitoring and a slow release are key steps to avoid a proximal deployment. There were no distal migrations in our study, which may lead to pulmonary artery occlusion.[17] The Compassion trial reports migration of SAPIEN valve in dilated RVOT.[25] Wireframe fracture in proximal flare in 3 (11%) patients did not affect the valve function. Unlike the Melody valve, in which competence was dependent on the stent-frame integrity, fracture of the proximal flare did not affect the

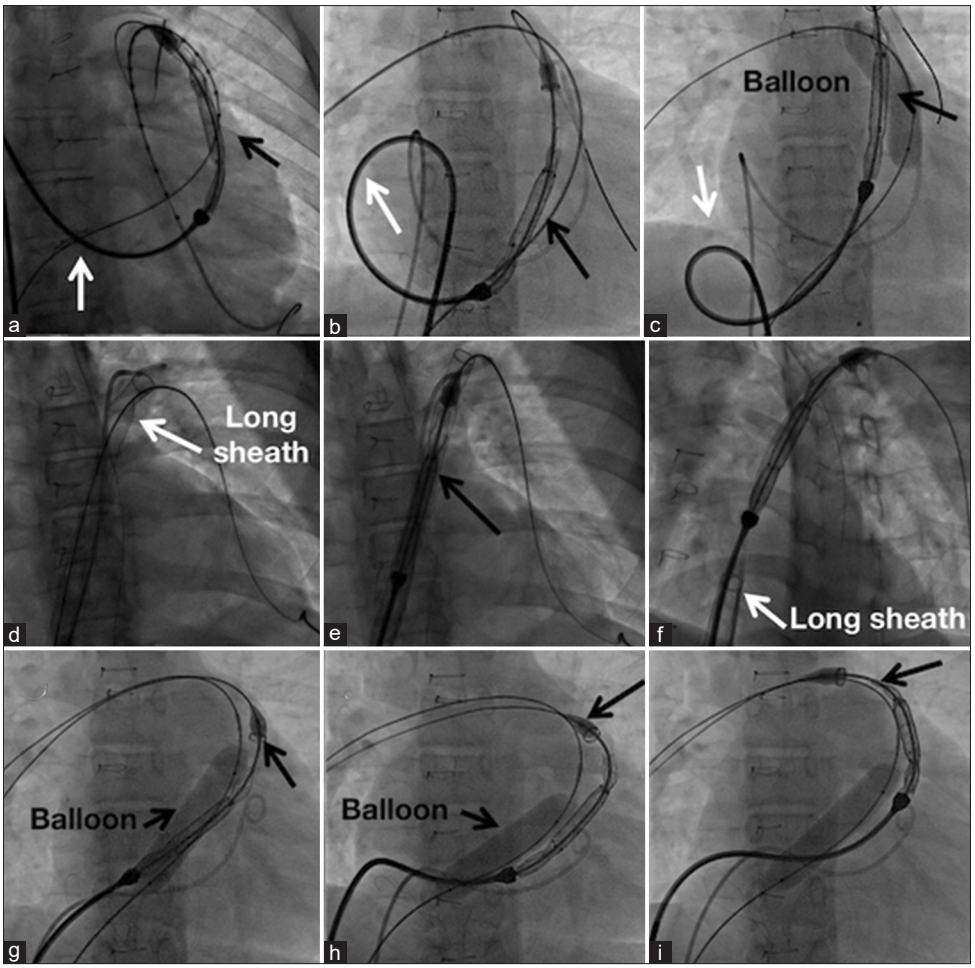

Figure 4: Modification of techniques to advance the valve delivery system. The large profile delivery system of Venus P-valve could be advanced to the outflow tract only with some manipulations by creating a large right atrial loop (a) that was slowly unwound (b) resulting in advance of the valve assembly. An inflated balloon (c) reduced the friction in the distal outflow. When a long 26F braided sheath was available (d), it allowed unhindered passage of the delivery system (e) and valve deployment was preceded by withdrawing the long sheath (f). Extreme tortuous left pulmonary artery was managed by right pulmonary artery deployment (g) where an inflated balloon (h) reduced the friction and allowed progressive advance (i) of the delivery system

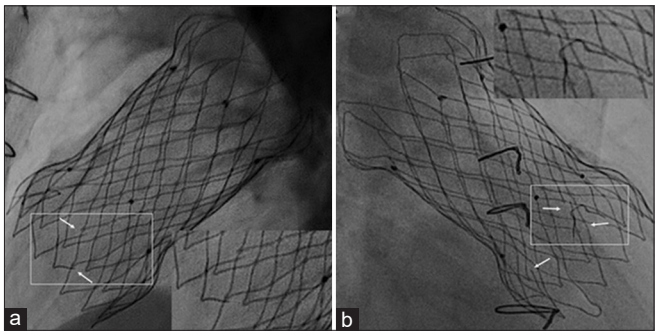

Figure 5: The thin nitinol frame in the proximal flare exposed to the contractile right ventricle showed wire-frame fractures on fluoroscopy in three patients. A magnified view in lateral view (a) and right anterior oblique view (b) shows three small fractures, magnified in the inserts. However, the function of the valve assembly that is present in the middle segment was not affected

function of the Venus P-valve located in the mid-zone.[17,28] Infective endocarditis in one patient after 4 years was managed without any impairment of valve function. Incidence of endocarditis in our cohort with a median follow-up of 46 months was relatively less compared to other reports. Early endocarditis after Venus P-valve recorded in 7% of patients in the Chinese study was comparable to an annual risk of 2% in the pooled analysis after Melody valve implantation.[12,29] In the Chinese study, one mortality and another patient needing surgery among four patients with infective endocarditis is of concern and needs meticulous patient education about dental hygiene and antibiotic prophylaxis.[14,30] Early withdrawal of aspirin after 6 months in the Chinese study was associated with pulmonary thromboembolism needing urokinase.[14] There were no thromboembolic episodes in our registry while using long-term dual antiplatelet therapy with 150 mg aspirin and 75 mg clopidogrel. Rapid discontinuation of aspirin after 6 months leading to thrombus formation on the valve leaflets is a known risk factor for endocarditis.[31]

Intermediate term valve function

The mean follow-up in our study was 47.8 ± 24.5 months

with the longest follow-up of 85 months, without any need for reintervention. The follow-up in this registry was longer than in the previous reports.[14,16,17] There was no significant increase in RVOT gradient or occurrence of significant regurgitation, suggesting good durability of the valve. The straight Venus P-valve available in larger sizes is a good alternative to Melody and SAPIEN valve in stented conduits. Continued surveillance is warranted to look for late mechanical disturbances in the valve frame.[32]

Limitations

The study has inherent bias related to any retrospective study. The procedural and follow-up protocols vary among institutions affected the analysis of data. Logistic reasons prevented routine CMR in all the patients and formal cardiopulmonary exercise testing. The parameters used for analysis differed from Group A and Group B patients, but both were presented together as they formed part of the Indian registry.

CONCLUSIONS

The procedural and follow-up experience of patients in this Indian registry showed safety and efficacy of straight and flared Venus P-valves used in appropriate situations. The straight design could be a safe and durable alternative to the Melody valve in prestented conduits. The flared design expanded the scope of percutaneous treatment to larger outflow tracts up to 34 mm. LPA stenosis was not an absolute contraindication. Long-term antiplatelet therapy may be a good strategy against valve thrombosis and endocarditis. The recent modification in the design overcame some of the reasons for previous technical failures. Further studies should focus on long-term durability and late complications.

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Conflicts of interest

There are no conflicts of interest.

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