

Mechanism of valve failure and efficacy of reintervention through catheterization in patients with bioprosthetic valves in the pulmonary position

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ABSTRACT

- Background** : Surgical and transcatheter bioprosthetic valves (BPVs) in the pulmonary position in patients with congenital heart disease may ultimately fail and undergo transcatheter reintervention. Angiographic assessment of the mechanism of BPV failure has not been previously described.
- Aims** : The aim of this study was to determine the mode of BPV failure (stenosis/regurgitation) requiring transcatheter reintervention and to describe the angiographic characteristics of the failed BPVs and report the types and efficacy of reinterventions.
- Materials and Methods** : This is a retrospective single-center review of consecutive patients who previously underwent pulmonary BPV placement (surgical or transcatheter) and subsequently underwent percutaneous reintervention from 2005 to 2014.
- Results** : Fifty-five patients with surgical (41) and transcatheter pulmonary valve (TPV) (14) implantation of BPVs underwent 66 catheter reinterventions. The surgically implanted valves underwent fifty reinterventions for indications including 16 for stenosis, seven for regurgitation, and 27 for both, predominantly associated with leaflet immobility, calcification, and thickening. Among TPVs, pulmonary stenosis (PS) was the exclusive failure mode, mainly due to loss of stent integrity (10) and endocarditis (4). Following reintervention, there was a reduction of right ventricular outflow tract gradient from 43 ± 16 mmHg to 16 ± 10 mmHg ($P < 0.001$) and RVp/AO ratio from 0.8 ± 0.2 to 0.5 ± 0.2 ($P < 0.001$). Reintervention with TPV placement was performed in 45 (82%) patients (34 surgical, 11 transcatheter) with no significant postintervention regurgitation or paravalvular leak.
- Conclusion** : Failing surgically implanted BPVs demonstrate leaflet calcification, thickness, and immobility leading to PS and/or regurgitation while the mechanism of TPV failure in the short- to mid-term is stenosis, mainly from loss of stent integrity. This can be effectively treated with a catheter-based approach, predominantly with the valve-in-valve technique.
- Keywords** : Bioprosthetic valve, interventional cardiology, pulmonary regurgitation, pulmonary stenosis, repaired tetralogy of Fallot, transcatheter pulmonary valve

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INTRODUCTION

The implantation of bioprosthetic valves (BPVs) in the pulmonary position is a surgical option for the management of right ventricular outflow tract (RVOT) dysfunction in congenital heart disease. This is understood to be a palliative procedure as structural valve deterioration (SVD) leading to pulmonary stenosis (PS), pulmonary regurgitation (PR), or both, ultimately develops at a high frequency requiring either surgical or catheter-based reintervention.^[1,2] It is reported, for example, that freedom from SVD (defined as need for reintervention or at least moderate PS or PR) after pulmonary valve replacement in tetralogy of Fallot patients is 54% at 7 years.^[3] The mechanisms of BPV failure in the aortic position are well described by noninvasive imaging and surgical explants. Valves can demonstrate diffuse intrinsic calcification of leaflets and commissures, as well as thickening and immobility of the leaflets.^[4] Further, surgical explants have demonstrated calcification, cusp tears, pannus formation, thrombus, and inflammation associated with infective endocarditis (IE).^[4-6] There are identified risk factors which are linked to SVD leading to valve dysfunction and/or the need for reintervention including patient comorbidities, younger age, valve characteristics including lack of antimineralization during preparation, and patient-prosthesis mismatch.^[3,7-12]

Recently, reports of life-threatening aortic stenosis from accelerated degeneration of Mitroflow BPVs in the aortic position in pediatric patients have prompted investigations of BPV use in children in the pulmonary position.^[4,13] At our center, most patients with BPV failure are referred for catheterization before surgical referral. Thus, we have the opportunity to acquire information about the hemodynamic function and integrity of the Mitroflow valve as well as other BPVs in the pulmonary position. The literature has not focused on the angiographic appearance of failed BPVs. Hence, our primary goal is to describe the mechanism of failure of various BPVs in the pulmonary position through hemodynamic and angiographic assessment in the catheterization laboratory. This, along with the types and efficacy of catheterization reintervention, will be presented.

MATERIALS AND METHODS

Study group

We performed a single-center retrospective chart review as approved by the Institutional Review Board on all consecutive patients who underwent transcatheter reintervention of surgically or transcatheter-implanted BPVs in the pulmonary position between 2005 and 2014. Data collection involved review of medical

records including all catheterization reports, surgical operative notes, transthoracic echocardiography (TTE) reports, cardiac magnetic resonance (CMR) reports, and catheterization angiograms. Variables collected included patient demographics, primary diagnosis, valve type, and precatheterization TTE and CMR data, if available. Catheterization data included indication, pre-/post-intervention hemodynamics including RVOT gradient, right ventricle systolic pressure (RVSP), and right ventricle: aortic pressure ratio (RVp/AO), interventions performed, adverse events, and occurrence and timing of future transcatheter or surgical reintervention.

Angiographic assessment

Fluoroscopic and angiographic appearance of the valves were reviewed by a single reader and assessed using a grading scale that was created based on a modification of previously described echocardiography criteria.^[4] The degree of leaflet calcification, thickness, and mobility were graded as follows: grading of leaflet calcification: 0 (no calcification), 1 (partial involvement of 1 leaflet), 2 (partial involvement of 2 or 3 leaflets), 3 (involvement of 1 leaflet), and 4 (complete involvement of 2 or 3 leaflets).

Grading of leaflet thickness: 0 (normal leaflet thickness), 1 (mild thickness, <2 mm of 1 leaflet), 2 (mild thickness of 2 or 3 leaflets), 3 (marked ≥ 2 mm thickness of 1 leaflet), and 4 (marked thickness of 2 or 3 leaflets).

Grading of leaflet immobility: 0 (normal leaflet opening), 1 (mild restriction of 1 leaflet), 2 (mild restriction of 2 or 3 leaflets), 3 (marked restriction of 1 leaflet), and 4 (marked restriction of 2 or 3 leaflets).

The location of the balloon waist in relation to the valve-sewing ring during balloon sizing/angioplasty was documented. Transcatheter pulmonary valves (TPVs) were further assessed for stent integrity, including fractures, compression, and luminal compromise.

Statistical analysis

Data were reported as median (range), frequency (percentage), or mean \pm standard deviation. Analysis of variables pre-/post-reintervention and between a heterogeneous group of Carpentier-Edwards (CE) (Edwards Lifesciences, Irvine, California, USA) bovine pericardial valves and Mitroflow A12/LX (Sorin S.p.A., Milan, Italy) valves was performed using Student's *t*-test or Wilcoxon rank-sum test, when appropriate. The strength of association between grading scale variables was assessed using Spearman's correlation coefficient. $P < 0.05$ was considered to be statistically significant. For patients with multiple catheterizations on the same valve, the data from the first procedure were used for analysis.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical

standards of the Institutional and/or National Research Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

RESULTS

Demographics

Fifty-five patients after surgical (41) or transcatheter (14) implantation of BPVs underwent 66 catheterization reinterventions during the study period. Their demographic and BPV information is summarized in Tables 1 and 2. Since 1996, 723 BPVs were surgically placed at our center in the pulmonary position including 230 CE bovine pericardial valves and 319 Mitroflow valves [Figure 1]. Since 2007, 245 TPVs (Melody, Medtronic Inc., Minneapolis, MN, USA)

Table 1: Demographic and anatomic data

	Median (range) or n (%)
Age (years)	17 (0.7-54)
Weight (kg)	56 (6.6-105)
Primary diagnosis	
Tetralogy of Fallot	39 (71)
Pulmonary stenosis	21
Pulmonary atresia	14
Absent pulmonary valve	3
Complete AV canal	1
Truncus arteriosus	8 (15)
Double outlet RV	3 (5)
D-transposition of the great arteries	2 (4)
Pulmonary atresia, intact ventricular septum	1 (2)
Valvar pulmonary stenosis	1 (2)
Aortic stenosis (status post-Ross procedure)	1 (2)
Outflow tract at the time of BPV placement	
RV-to-PA conduit	26 (47)
Native, transannular patch	24 (44)
Native	4 (7)
RV-to-MPA connection	1 (2)

AV: Atrioventricular, MPA: Main pulmonary artery, BPV: Bioprosthetic valve, PA: Pulmonary artery

Table 2: Bioprosthetic valve data

	n (%)
BPV type	
CE bovine pericardial	20 (36)
Perimount Magna	9
Perimount	7
Unspecified	4
Sorin Mitroflow A12/LX	17 (31)
Medtronic Melody, transcatheter implant	14 (25)
CE porcine	2 (4)
Medtronic Melody, surgical implant	1 (2)
Medtronic Hancock porcine	1 (2)
BPV size, surgical implants	
25 mm	14 (34)
23 mm	7 (17)
19 mm	7 (17)
27 mm	5 (12)
21 mm	5 (12)
29 mm	1 (2)
16 mm	1 (2)
12 mm, Melody, intraoperative dilation	1 (2)

BPV: Bioprosthetic valve, CE: Carpentier-Edwards

were implanted in the pulmonary position with an incidence of catheterization reintervention of 6.1%. This is comparable to the estimated incidence of catheter-based reinterventions at our center on surgically placed valves during the same time period of 6.3%.

Noninvasive imaging

Most patients underwent precatheterization noninvasive imaging including TTE (92%) and/or CMR (36%) and the results of these tests are summarized in Table 3. By TTE, the median RVOT peak gradient was 55 mmHg (21-93) and 65% of patients had at least moderate PR. No TPV patients had more than mild PR by echo or CMR. Most patients had at least mild RV dysfunction by echo (69%), with a median RV ejection fraction of 43% (15-59) by CMR.

Catheterization of surgically implanted valves

In the surgical group, the indication for catheter reintervention was SVD represented as only PS (16; 32%), only PR (at least moderate) (7; 14%), or both (27; 54%) [Table 4]. The median RVOT gradient, RVSP, and RVp/AO were 38 mmHg (11-75), 70 mmHg (40-140), and 0.77 (0.41-1.14), respectively. Fluoroscopic and angiographic assessment found the evidence of leaflet calcification, thickness, and immobility with mean severity grades of 1.67 ± 1.23 , 2.04 ± 1.38 , and 3.35 ± 1 , respectively [Figure 2 and Table 5]. The median grades for leaflet calcification, thickness, and immobility were 2, 2, and 4, respectively. The calcification, when present, was most apparent at the leaflet tips, the leaflet cusps, and occasionally involved the commissures [Figure 3]. Further assessment of the Mitroflow valves found that the immobile leaflets appeared to freeze in the partially open position with the leaflet tips being the primary level of obstruction. This yielded a supravalvar balloon waist at this location, necessitating a more distal TPV placement in relation to the sewing ring [Figure 4].

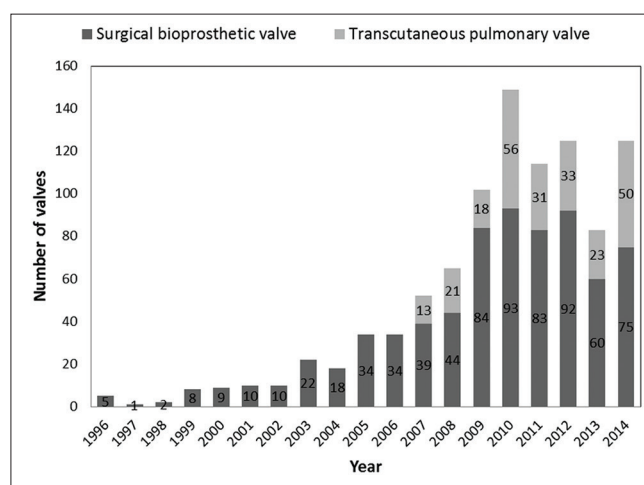


Figure 1: Number of surgical bioprosthetic pulmonary valve replacements and transcatheter pulmonary valve implantations

Table 3: Precatheterization noninvasive imaging data

	Median (range) or n (%)
Transthoracic echocardiography (n=61, 92%)	
Tricuspid regurgitation	
Trivial to mild	33 (57)
Moderate to severe	25 (43)
Estimated RV pressure mmHg*	75 (45-115)
RV pressure/systolic BP, %**	67 (36-101)
Peak RVOT gradient, mmHg	55 (21-93)
Pulmonary regurgitation	
Trivial to mild	15 (35)
Moderate to severe	28 (65)
Right ventricular dysfunction (qualitative)	
None	18 (31)
Mild	16 (27)
Moderate	12 (20)
Severe	13 (22)
Cardiac magnetic resonance (n=24, 36%)	
Pulmonary regurgitation fraction, %	24 (0-41)
RV end-diastolic volume indexed, ml/m ²	161 (109-342)
RV end-diastolic volume indexed, Z-score	6 (1.7-18.2)
RV ejection fraction, %	43 (15-59)
Left ventricle ejection fraction, %	54 (29-62)

Estimated RV pressure=tricuspid regurgitation jet (mmHg) + assumed right atrial pressure of 5 mmHg. *n=54, **n=49. RV: Right ventricle, RVOT: Right ventricular outflow tract, BP: Blood pressure

Table 4: Catheterization data

	n (%)
Indication for catheterization	
Surgical implant (n=50)	
Pulmonary stenosis only	16 (32)
Pulmonary regurgitation only	7 (14)
Pulmonary stenosis and regurgitation	27 (54)
Secondary indication: RV dysfunction	31 (62)
Transcatheter implant (n=16)	
Pulmonary stenosis only	16 (100)
Secondary indication: RV dysfunction	13 (81)
Intervention type	
Surgical implant	
Balloon dilation including sizing	50 (100)
Melody valve implantation	34 (68)
Prestented	4 (12)
Coronary assessment	28 (80)
Stent placement only	2 (4)
Transcatheter implant	
Melody valve implantation, prestented	12 (75)
Stent placement only (both endocarditis)	2 (13)
Balloon dilation only	2 (13)
Other interventions	
Branch PA angioplasty	15 (23)
Branch PA stent placement	2 (3)
Other (coil APC, device closure, biopsy, chest tube)	6 (9)

RV: Right ventricle, APC: Aorto-pulmonary collateral, PA: Pulmonary artery

Some Mitroflow valves had infolding/crowding of posts (leaflet suture lines) contributing to the obstruction. Finally and not unexpectedly, the sewing ring was not expandable by the balloons (typically not high pressure) used during interventions. Regarding the CE bovine pericardial valves, the leaflets were not as easily identifiable by fluoroscopy and angiography. This was particularly true in the older

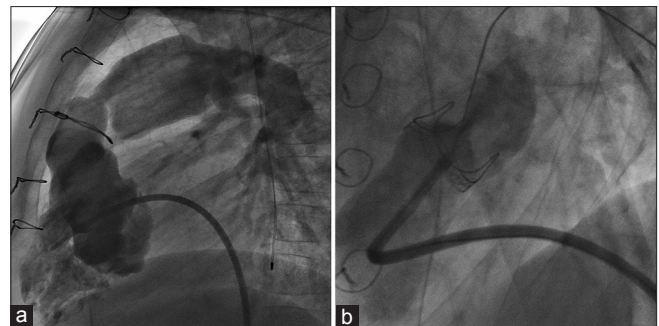


Figure 2: (a) Thickened, immobile Mitroflow leaflets. (b) Thickened, immobile Carpentier-Edwards leaflets

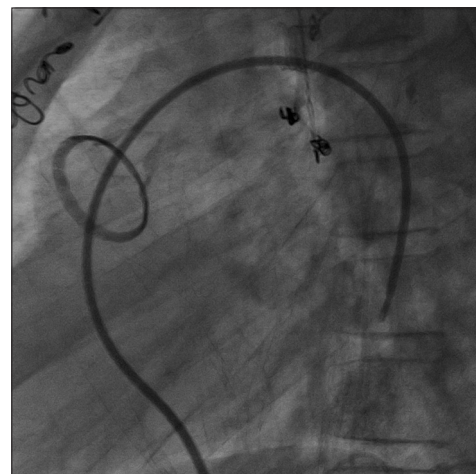


Figure 3: Mitroflow valve with calcification of leaflets

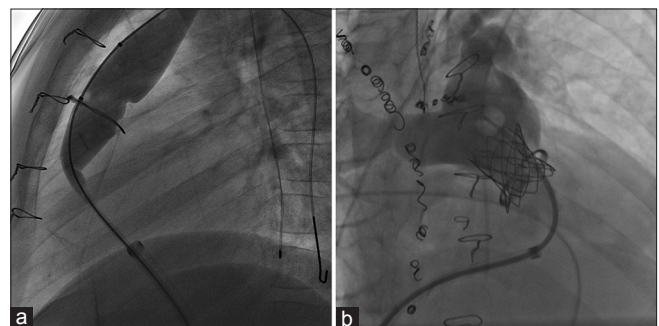


Figure 4: (a) Supra-valvar balloon waist of Mitroflow valve. (b) Melody within Mitroflow valve

valves with free insufficiency. The visualized immobile leaflets were typically partially open or in the closed position with the waist of the balloon typically just above the ring. Balloon dilation, in some instances expanded the posts, but not the ring, typically with recoil of the posts. Among this cohort of patients, the Mitroflow A12/LX valves as compared to the CE bovine pericardial valves had a higher mean grade of leaflet thickness ($P < 0.001$) and leaflet immobility ($P = 0.04$) [Table 5]. A higher grade of leaflet calcification ($r = 0.409, P = 0.01$) or leaflet thickness ($r = 0.827, P < 0.001$) correlated with a higher grade of leaflet immobility.

Table 5: Assessment of surgically implanted bioprosthetic valves

Valve characteristic	Total (n=41)	Mitroflow (n=16)	CE pericardial (n=20)	P
Time since implant (years)	6±4.6	2.9±1.6	8.2±4.8	
Calcification	2 (0-4)	2 (0-4)	2 (0-4)	0.79
Thickness	2 (0-4)	3 (1-4)	1 (0-4)	0.001
Immobiity	4 (0-4)	4 (2-4)	3 (0-4)	0.04
RVOT gradient (mmHg)	40±15	40±13	39±15	0.75
Pulmonary regurgitation	2 (0-3)	2 (1-3)	2 (0-3)	0.31
Regurgitant fraction, %	28±11	27±13	28±12	0.81

Data presented as mean±SD or median (range). Mitroflow n=16 as one angiography unavailable for review. Pulmonary regurgitation (none/trivial=0, mild=1, moderate=2, severe=3) based on patients who had precatheterization echocardiography (Mitroflow; n=15, CE; n=14). Regurgitant fraction based on patients who had precatheterization cardiac magnetic resonance (Mitroflow; n=7, CE; n=7). SD: Standard deviation, CE: Carpentier-Edwards, RVOT: Right ventricular outflow tract

All interventions (n = 50) included balloon dilation and/or balloon sizing of the bioprosthetic valve, followed most commonly by TPV implantation (n = 34; 68%), four of which were prestented [Table 4]. Prestenting was performed to relieve a subvalvar obstruction (1), prevent recoil of thick leaflets and valve posts to optimize TPV landing zone (2) and resolve an acute angle from valve location in distal RVOT (1). Stent placement only was also used to manage obstruction to the pulmonary arteries from a distally placed bioprosthetic valve [Figure 5]. Of note, the frequency of use of TPV increased from 30% to 74% following its approval for dysfunctional conduits in 2010.

Catheterization of transcatheter-implanted valves

The patients with TPVs underwent re-catheterization at a median of 2 years (0.7–5) exclusively due to PS. The two mechanisms of PS in these patients were loss of stent integrity (10), and endocarditis (4) [Table 4]. None of the patients with valve fracture had undergone prestenting during their initial implantation. The mean RVOT gradient, RVSP, and RVp/AO were 50 mmHg (30–80), 78 mmHg (55–110), and 0.9 (0.5–1.1), respectively. Narrowing of the stents leading to obstruction with or without fracture demonstrated anterior/posterior narrowing with at times further dynamic compression and loss of luminal integrity. Valves with endocarditis demonstrated severe stent stenosis due to circumferential filling defect. One patient with endocarditis had visibly thickened (Grade 2), immobile (Grade 4) leaflets without calcification. Another patient had a TPV within a 16 mm bioprosthetic valve (13-year-old, body surface area of 1.46 m²) with a balloon waist localized at the valve ring that did not significantly resolve the gradient, suggesting inadequate effective orifice area for patient size (i.e., patient–prosthetic mismatch). Interventions included additional TPV implantation following prestenting (12), stent placement only (2), or balloon angioplasty only (2) [Table 4].

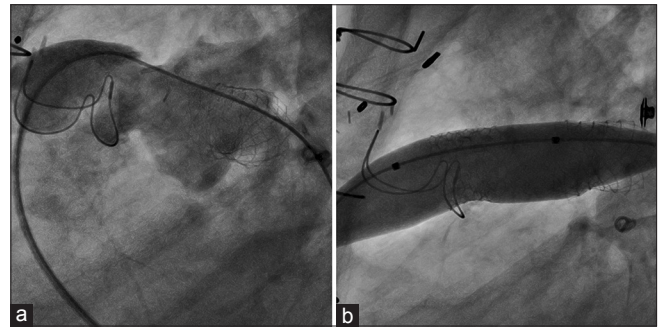


Figure 5: (a) Distal bioprosthetic valve with acute take off of pulmonary arteries. (b) Stent placement

Postintervention

Following intervention on the surgical and transcatheter valves, there was an overall reduction of the RVOT gradient from 43 ± 16 mmHg to 16 ± 10 mmHg ($P < 0.001$), RVSP from 76 ± 20 mmHg to 52 ± 13 mmHg ($P < 0.001$), and RVp/AO ratio from 0.8 ± 0.2 to 0.5 ± 0.2 ($P < 0.001$) as well as an increase in cardiac index when measured from 2.9 ± 0.6 L/min/m² to 3.5 ± 0.8 L/min/m² ($P < 0.001$). There was no angiographic evidence of more than trivial PR or paravalvular leak in patients who underwent TPV implantation (n = 45).

Postcatheterization reintervention

Following catheter reintervention, nine patients with surgically placed BPVs underwent an additional transcatheter reintervention at 2.6 years (0.2–5.75). Eight of these patients subsequently had TPV implantation. Following TPV implantation in the surgical bioprosthetic valve group, freedom from reintervention or death was 94% (32/34 patients) at a median follow-up of 1.3 years (0–6.1).

Eight out of total 55 patients underwent surgical reintervention, three within a week of catheterization in the patients with endocarditis. One patient had balloon angioplasty only of the bioprosthetic valve prior to scheduled surgery the following day. The remaining four patients had surgical pulmonary valve replacement at 2.4 years (0.1–5.1) postinitial catheterization intervention. In the entire cohort, there were two deaths in follow-up, both unrelated to the cath procedure.

Adverse events

There were 19 adverse events during 16 of the 66 (24%) catheterizations; most commonly rebleed postcatheterization without the need for transfusion (6, 32%) and transient rhythm disturbances (4, 21%). The most serious event was a distal pulmonary artery (PA) tear requiring coil embolization of a segmental branch secondary to wire injury.^[14] There were no instances of coronary compression.

DISCUSSION

Our study characterized BPV failure in the pulmonary position using catheterization hemodynamics and angiographic appearance among patients referred for reintervention; further, we described the type and efficacy of the reintervention. Our recent awareness of accelerated structural valve degeneration in Mitroflow BPVs in the aortic position served as the precipitant of this investigation though we chose to broaden our review to all types of BPVs utilized in the pulmonary position.^[4]

The mechanism of failure exhibited by BPVs implanted surgically versus TPV was distinct. Surgical valves demonstrated leaflet failure causing stenosis and/or regurgitation while TPVs had stent failure or endocarditis leading to PS only. There was no TPV leaflet failure in the absence of stent fracture or endocarditis. The surgical BPVs demonstrated leaflet calcification, thickening, and immobility, with the latter being the most striking finding. Furthermore, we found that higher grades of calcification and thickening were associated with higher grades of immobility, suggesting changes to the biomaterial of the valve are what lead to its mechanical dysfunction. The angiographic appearance of failed BPVs in our study is consistent with those described by Butany *et al.* in two separate reviews of a limited number of surgically explanted CE Perimount and Mitroflow A12 valves.^[6,15] Further, when comparing the Mitroflow A12/LX and a heterogeneous group of CE bovine pericardial valves in our cohort, the Mitroflow BPVs had higher grades of leaflet thickness and immobility. This finding of Mitroflow leaflet thickening in the pulmonary position is consistent with the progressive leaflet thickening seen in failed Mitroflow valves in the aortic position.^[4,6,13] It is suggested that the lack of antimicrobialization techniques in the preparation of the original Mitroflow valves has contributed to their dysfunction; something the new Mitroflow DL valves aim to avoid.^[7] Patient factors may also contribute to valve failure. For instance, a patient-prosthetic mismatch creates undue turbulence through the orifice leading to an inadequate effective orifice not only through the sewing ring, but also as SVD develops, exacerbating the stenosis.^[9,11] Further, SVD may also result from distal placement of the valve in the RVOT, which can cause crowding of the posts, decrease in leaflet excursion, and/or obstruction to the pulmonary arteries.^[16]

From a clinical standpoint, this study demonstrates the potential utility of the angiographic assessment of surgical BPVs as another modality in the evaluation of BPV dysfunction. Specifically, in the absence of intracardiac echocardiography and/or inadequate imaging from other modalities, for instance, the angiographic appearance of the valve paired with the hemodynamic data can provide a thorough assessment of BPVs. The acquired data may

assist in decision-making regarding the need and type of surgical or transcatheter reintervention.

In our cohort, there were no TPVs that demonstrated pure leaflet dysfunction and angiographic degenerative changes with an intact stent and no endocarditis. Ten patients in this study, who were part of the early experience in the investigational device exemption trial, lost their stent integrity due to inadequate conduit rehabilitation including prestenting. This TPV failure, reported by McElhinney *et al.* in 2011, has decreased in association with change in implantation techniques.^[17] It will thus be interesting to observe how the TPV performs in a long term and whether the leaflets will ultimately demonstrate angiographic findings similar to the surgical BPVs. The remaining four TPVs in our cohort had IE with an in-stent circumferential filling defect assumed to be vegetation or thrombus formation. Three of the four patients with endocarditis were palliated with catheter-based reinterventions in an effort to reduce the severity of the RVOT obstruction and RVSP to lower the risk of surgery. The true incidence of IE is unknown partly due to inconsistent definitions and reporting rates. McElhinney *et al.* reported the incidence of definite or presumed IE in 311 patients following Melody valve implantation to be 5%.^[18] According to Buber *et al.*, whose single-center experience had a bacterial bloodstream infection incidence of 9.5%, determined patients with previous bloodstream infections, higher mean RVOT gradients or RVOT wall irregularities may be associated with an increased incidence of the said infections.^[19]

The most commonly used reintervention in our study was TPV implantation which reduces the stenosis and resolves the regurgitation as long as the effective orifice area is appropriate for the patient. Prestenting is typically unnecessary using this valve-in-valve technique.^[17] The success and technical aspects of this approach in the pulmonary position were demonstrated by Gillespie *et al.* in 2012 with excellent short-term outcomes.^[16] Their study, which included 104 patients, 38 CE bovine pericardial valves, 38 Medtronic Hancock conduits, 3 Mitroflow valves, and 25 others, reported a freedom from reintervention of 92% \pm 5% at 2 years. Ongoing follow-up is needed to determine the long-term durability of the TPVs using this implantation technique. Furthermore, studies with larger sample sizes are needed to compare the incidence of failure of the different types of BPVs in the pulmonary position.

Limitations

This was a single-center, retrospective study with a small sample size and a short follow-up time. This is a highly selected population since inclusion criteria limited the population to those not only referred to catheterization, but who also underwent a transcatheter intervention. Because this is a retrospective study, there were no

predefined criteria for referral to catheterization or for standardizing when an intervention or reintervention was carried out. Furthermore, because the study period overlaps the time before and after the Melody valve was available, older valves may have been referred for catheterization relatively later. Additional interventions performed during the same procedure, such as branch PA angioplasty, may have assisted in reducing the RVSP and RVp/AO ratio making the RV-to-PA gradient in certain cases a more reliable estimate of success.

CONCLUSION

Failing BPVs in the pulmonary position demonstrate increased leaflet calcification, thickness, and immobility leading to both PS and regurgitation as assessed by catheterization and angiography. The Mitroflow A12/LX BPVs as compared to a heterogeneous group of CE bovine pericardial valves tend to have more severe leaflet thickness and leaflet immobility. Failing surgically and transcatheter-implanted valves can be effectively treated with a catheter-based approach, predominantly with the valve-in-valve technique.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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