

Transcatheter Valve-in-Valve Implantation for Failed Bioprosthetic Heart Valves

John G. Webb, MD; David A. Wood, MD; Jian Ye, MD; Ronen Gurvitch, MD; Jean-Bernard Masson, MD; Josep Rodés-Cabau, MD; Mark Osten, MD; Eric Horlick, MD; O. Wendler, MD; Eric Dumont, MD; Ronald G. Carere, MD; Namal Wijesinghe, MD; Fabian Nietlispach, MD; Mark Johnson, MD; Christopher R. Thompson, MD; Robert Moss, MD; Jonathon Leipsic, MD; Brad Munt, MD; Samuel V. Lichtenstein, MD, PhD; Anson Cheung, MD

Background—The majority of prosthetic heart valves currently implanted are tissue valves that can be expected to degenerate with time and eventually fail. Repeat cardiac surgery to replace these valves is associated with significant morbidity and mortality. Transcatheter heart valve implantation within a failed bioprosthesis, a “valve-in-valve” procedure, may offer a less invasive alternative.

Methods and Results—Valve-in-valve implantations were performed in 24 high-risk patients. Failed valves were aortic (n=10), mitral (n=7), pulmonary (n=6), or tricuspid (n=1) bioprostheses. Implantation was successful with immediate restoration of satisfactory valve function in all but 1 patient. No patient had more than mild regurgitation after implantation. No patients died during the procedure. Thirty-day mortality was 4.2%. Mortality was related primarily to learning-curve issues early in this high-risk experience. At baseline, 88% of patients were in New York Heart Association functional class III or IV; at the last follow-up, 88% of patients were in class I or II. At a median follow-up of 135 days (interquartile range, 46 to 254 days) and a maximum follow-up of 1045 days, 91.7% of patients remained alive with satisfactory valve function.

Conclusions—Transcatheter valve-in-valve implantation is a reproducible option for the management of bioprosthetic valve failure. Aortic, pulmonary, mitral, and tricuspid tissue valves were amenable to this approach. This finding may have important implications with regard to valve replacement in high-risk patients. (*Circulation*. 2010;121:1848-1857.)

Key Words: catheter ■ mitral valve ■ surgery ■ heart valves

Bioprosthetic heart valves are often favored over more durable mechanical valves because of a lower risk of thrombotic and bleeding events and the desire to avoid anticoagulation.¹ With time, bioprosthetic tissue can be expected to deteriorate and eventually fail. Reoperation has been the standard treatment for prosthetic valves that develop severe stenosis or regurgitation; however, repeat surgery may carry significant risks.¹ The Society of Thoracic Surgeons risk calculator predicts that an 80-year-old man with no comorbidities has an approximate mortality risk of 5% for aortic reoperation and 10% for mitral reoperation and a major morbidity risk of 20% and 23%, respectively (<http://www.sts.org>). These risks increase dramatically in the presence of comorbidities.^{2,3}

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Transcatheter heart valve (THV) implantation has found rapid acceptance as an alternative to conventional surgical

valve replacement for patients with native aortic valve stenosis.⁴ THV implantation might also represent an attractive option for patients with failing bioprosthetic valves (Figure 1).^{5,6} Isolated single case reports of what has been referred to as “valve-in-valve” implantation in this setting have appeared from our groups and others.⁷⁻¹¹ Here, we describe a multicenter experience with valve-in-valve implantation for failed aortic, mitral, pulmonary, and tricuspid bioprosthetic valves.

Methods

Patients

Valve-in-valve procedures were performed in 24 patients (Table 1). Cases were performed in Vancouver (n=18), Toronto (n=4), and Quebec City (n=1) in Canada, as well as London in the United Kingdom (n=1). All THV implants were performed for clinical reasons under local compassionate release protocols. Informed written consent was required. Acceptance was by consensus among teams of cardiologists and cardiac surgeons at the individual centers that patients were at

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From St Paul's Hospital, University of British Columbia, Vancouver, British Columbia, Canada (J.G.W., D.A.W., J.Y., R.G., J.-B.M., R.G.C., N.W., F.N., M.J., C.R.T., R.M., J.L., B.M., S.V.L., A.C.); Quebec Heart and Lung Institute, Quebec City, Quebec, Canada (J.R.-C., E.D.); Toronto General Hospital, Toronto, Ontario, Canada (M.O., E.H.); and King's College Hospital, London, UK (O.W.).

This is a retrospective multicenter registry experience of clinical cases done under palliative approval programs.

The online-only Data Supplement is available with this article at <http://circ.ahajournals.org/cgi/content/full/CIRCULATIONAHA.109.924613/DC1>.

Correspondence to John G. Webb, MD, St. Paul's Hospital, 1081 Burrard St, Vancouver, BC, Canada V6Z 1Y6. E-mail john.webb@vch.ca

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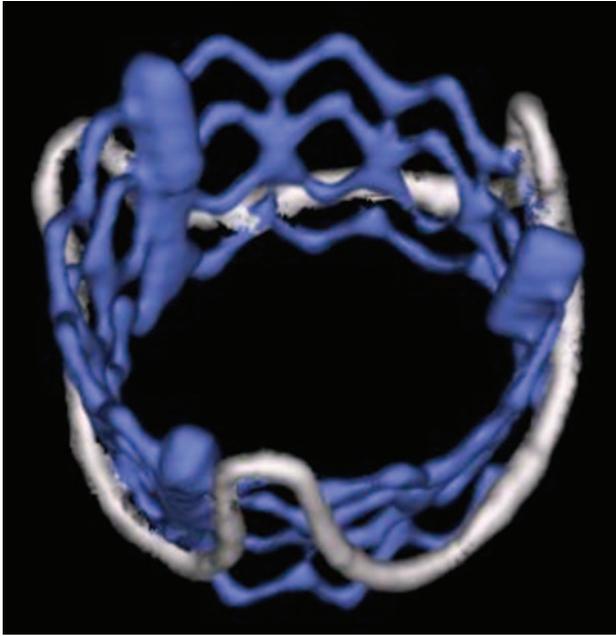


Figure 1. A 3-dimensional, volume-rendered, subtracted computed tomography image displaying a transcatheter valve (blue, SAPIEN THV) centrally deployed within a surgical bioprosthetic aortic valve (white, Carpentier-Edwards valve) in patient 12.

very high risk or were ineligible for surgery. Surgical reasons for determination of high risk included ≥ 2 prior thoracotomies in 7, severe pulmonary hypertension in 7, complex congenital cardiac disease in 6, severe double-valve disease in 5, hepatic cirrhosis in 2, severe coronary disease in 2, malignancy in 1, and carcinoid syndrome in 1. In addition, a subjective impression of frailty was documented by surgeons in 7 elderly patients. Patients with failed aortic and mitral bioprostheses had Society of Thoracic Surgeons procedural mortality estimates of $10.8 \pm 2.8\%$ and $14.9 \pm 5.2\%$ and logistic EuroSCORES of $31.1 \pm 9.7\%$ and $30.6 \pm 4.1\%$.

Procedure

Balloon-expandable Cribier-Edwards, SAPIEN, or SAPIEN XT THVs (Edwards Lifesciences Inc, Irvine, Calif) were used (Figure 2 and Movie I of the online-only Data Supplement).¹² Aortic and mitral valve-in-valve procedures were performed using a transapical or transarterial approach (Figure 3). Pulmonary procedures were performed with percutaneous transvenous access. The single tricuspid valve procedure was performed through a thoracotomy with direct right atrial access. A general anesthetic, transesophageal echocardiography (TEE), and rapid ventricular pacing to reduce cardiac output during deployment were routine, with the exception of some of the pulmonary implants. Balloon valvuloplasty was performed before implantation in patients with severely stenotic valves but not in patients with predominant regurgitation. Cardiopulmonary support was not used. Valve-in-valve THVs implanted had a nominal external diameter that matched or exceeded the reported internal diameter of the failed prosthesis.

Definitions

Major adverse cardiac and cerebrovascular events were defined as first occurrence of death, myocardial infarction, stroke, or renal failure. Myocardial infarction was a clinical diagnosis of infarction with new ECG changes and biomarker elevation or emergency revascularization. Renal failure was new long-term dialysis lasting >30 days. Stroke was a new neurological deficit lasting >24 hours with a brain imaging study showing infarction. Major bleeding was bleeding causing death or permanent injury or requiring >3 U packed red blood cells. Device success was successful delivery and deployment of the device and retrieval of the delivery catheter,

resulting in improvement in valve function. Procedure success was device success and no occurrence of in hospital or 30-day death,

Statistical Analysis

Continuous variables are expressed as mean \pm SD when normally distributed and as medians with interquartile ranges (quartile 1 through 3) when not normally distributed. The differences in the means of continuous variables before and after procedures were assessed by paired Student *t* tests or by applying the Wilcoxon signed-rank test for ordinal values. Analyses were performed with SPSS version 17.0 (SPSS Inc, Chicago, Ill). The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

Aortic Procedure

Valve-in-valve implantations in the setting of degenerated, surgically implanted aortic prostheses were performed in 10 patients (Table 2). In the initial percutaneous aortic procedure, the THV was positioned within the outflow portion of the surgically implanted valve but did not overlap the sewing ring (Figure 4). Balloon dilation of the THV resulted in splaying of the surgical valve struts and ejection of the balloon and THV. The THV was withdrawn with the partially inflated delivery balloon and then over-expanded to secure it within an area of the aortic arch free of side branches. It appeared that more coaxial alignment at the time of deployment might be achieved by a transapical approach. Consequently, transapical access was gained, and having learned from the initial attempt, we positioned the THV more coaxially and more ventricularly to overlap the sewing ring of the surgically implanted prosthesis. All 10 patients remained alive at the 30-day follow-up (mean predicted operative mortality according to Society of Thoracic Surgeons, $10.0 \pm 5.2\%$; logistic EuroSCORE, $30.4 \pm 9.7\%$). All 10 aortic patients remained alive at a median follow-up of 83 days (interquartile range, 30 to 248 days; longest follow-up, 891 days).

Mitral Procedure

A first-in-human attempt using a percutaneous transseptal approach was unsuccessful (Figure 5). Noncoaxial and too ventricular positioning of the THV within the surgically implanted prosthesis resulted in embolization. The THV was maintained on the guidewire within the left ventricle, facilitating emergent conversion to conventional surgery. The procedure was prolonged, and the patient died of multisystem failure the next day. In the second patient, an open transatrial approach was attempted.⁵ Stable cannulation and coaxial positioning within the mitral prosthesis could not be accomplished, and the procedure was converted to a transapical approach. Although the THV was successfully implanted, the procedure was prolonged and entailed bilateral thoracotomy. The patient died on day 45.

After this discouraging initial experience with the transseptal and transatrial approaches, subsequent procedures were performed with transapical access. All 5 subsequent mitral implantations were successfully and relatively easily accomplished, and all patients were alive at the 30-day follow-up (Table 3) and remained alive at a median follow-up of 72

Table 1. Clinical Characteristics at Baseline

Patient	Patient Age, y	Valve Position	Valve Age, y	STS Score	Logistic EuroSCORE	Prior Revascularization	Prior Thoracotomy	Diabetes Mellitus	eGFR ml/min	LVEF
1	85	Mitral	9	19.6	31.2	Yes	2	No	50	70
2	80	Mitral	7	18.5	37.3	Yes	1	No	28	65
3	78	Mitral	11	9.2	32.2	Yes	1	No	73	70
4	80	Mitral	13	11.9	28.1	No	1	No	60	55
5	84	Mitral	9	19.0	32.2	Yes	1	No	50	65
6	73	Mitral	24	18.5	24.1	No	2	No	44	55
7	77	Mitral	11	7.3	29.3	Yes	1	Yes	86	60
8	87	Aortic	10	10.2	31.0	Yes	1	No	58	65
9	83	Aortic	26	10.2	38.0	Yes	1	No	36	35
10	85	Aortic	13	11.5	39.0	Yes	1	No	29	45
11	86	Aortic	23	10.8	32.7	Yes	2	No	68	60
12	86	Aortic	17	10.2	32.7	Yes	2	Yes	34	65
13	83	Aortic	14	10.8	46.2	No	1	No	46	35
14	78	Aortic	7	4.5	19.5	Yes	1	No	58	60
15	84	Aortic	3	12.2	23.5	No	1	No	20	70
16	82	Aortic	10	11.1	34.1	No	1	No	74	65
17	67	Aortic	25	16.0	13.9	No	1	No	39	50
18	27	Pulmonary	22	N/A	N/A	No	4	No	109	65
19	32	Pulmonary	13	N/A	N/A	No	3	No	115	55
20	28	Pulmonary	3	N/A	N/A	No	2	No	...	63
21	31	Pulmonary	7	N/A	N/A	No	3	No	119	76
22	52	Pulmonary	25	N/A	N/A	No	2	No	114	41
23	37	Pulmonary	27	N/A	N/A	No	1	No	76	45
24	48	Tricuspid	7	N/A	N/A	No	2	No	54	65

STS indicates Society of Thoracic Surgeons; eGFR, estimated glomerular filtration rate; and LVEF, left ventricular ejection fraction. Revascularization includes surgical and percutaneous.

days (interquartile range, 30 to 120 days; longest follow-up, 345 days; Table 4).

Mitral transcatheter procedures were performed in a manner similar to that described for aortic valve implantation.¹³ After left ventricular puncture, fluoroscopy and TEE imaging facilitated placement of a standard J-tipped guidewire and arterial sheath through the prosthetic mitral valve (Figure 6). They were exchanged for a stiffer exchange-length guidewire (Amplatz Extra Stiff, Cook Inc, Bloomington, Ind) with a distal tight loop

positioned in the left atrium. A standard 26F transcatheter valve delivery system (Ascendra, Edwards Lifesciences Inc) was then advanced into the left ventricle. The THV was positioned with the use of both fluoroscopic and TEE guidance (Figure 7). In 1 patient with severe stenosis, it was necessary to pass the dilator and sheath through the prosthesis into the left atrium. The THV was then introduced directly into the left atrium and withdrawn into the stenotic mitral prosthesis where it was deployed.

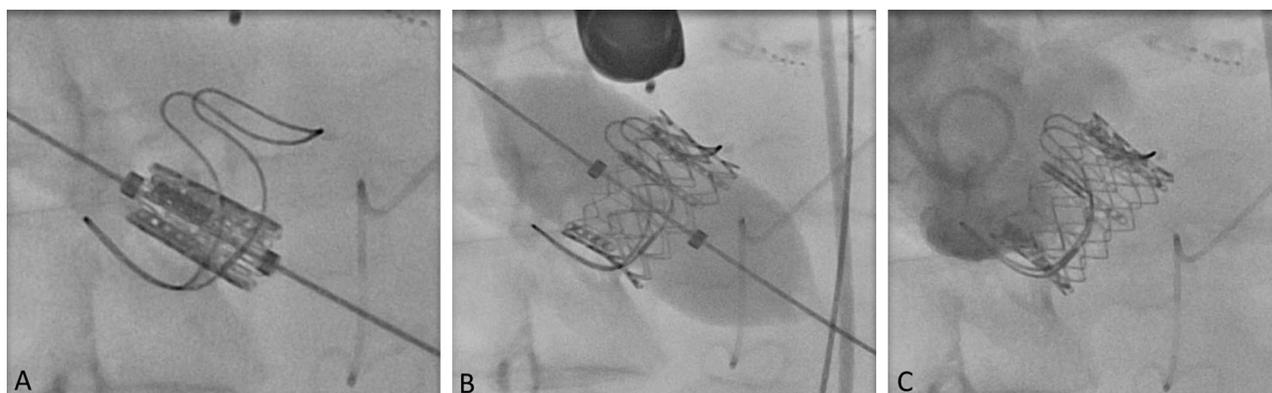


Figure 2. A, Fluoroscopic images during positioning of a transcatheter valve (SAPIEN 23-mm THV). The wire frame of a degenerated surgical bioprosthesis (Carpentier-Edwards 23 mm) is visible. The prosthetic sewing ring below the valve struts is radiolucent. B, The balloon-expandable THV is deployed and fixed within the sewing ring. C, Aortography demonstrates a competent valve (patient 9).

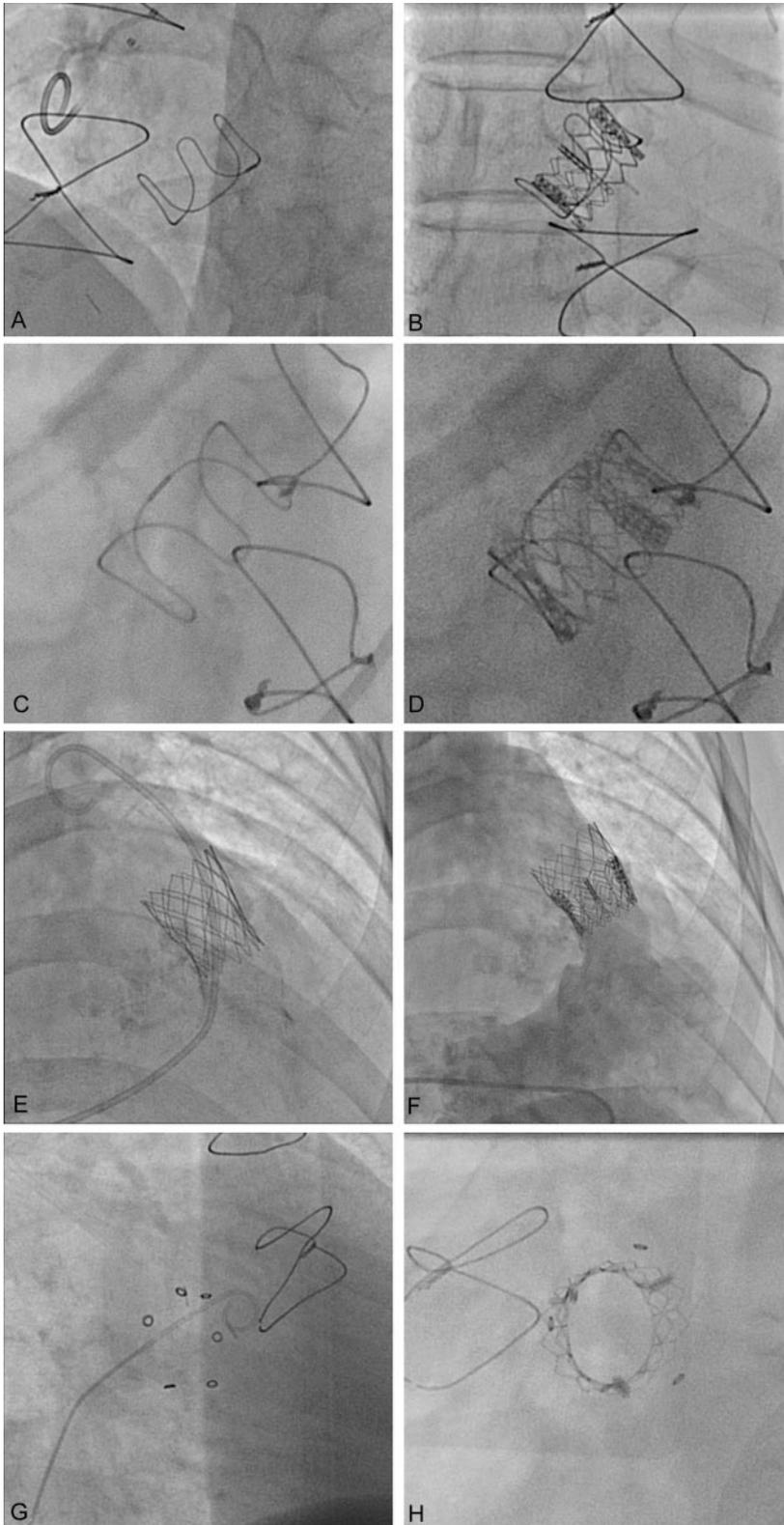


Figure 3. Fluoroscopic images before (left) and after (right) valve-in-valve implantation. A, Aortic Carpentier-Edwards 25-mm porcine valve. B, SAPIEN 23-mm THV (patient 8). C, Mitral Carpentier-Edwards 27 mm. D, SAPIEN 23-mm THV (patient 6). E, Pulmonary homograft and conduit with Palmaz stent. F, Cribier-Edwards 23-mm THV (patient 23). G, Tricuspid Medtronic Mosaic 27 mm. H, SAPIEN 26-mm THV (patient 29).

Pulmonary Procedure

Percutaneous femoral venous access allowed access to the failed pulmonary bioprosthesis in all 6 patients (Table 1). The stenotic bioprosthesis and adjacent conduit were first stented to provide a sufficiently long landing zone for the relatively short (15 to 16 mm long) SAPIEN THV (Figure 3). All patients remained

alive at a median follow-up of 185 days (interquartile range, 158 to 655 days; longest follow-up, 1045 days; Table 4).

Tricuspid Procedure

A patient with multiple comorbidities presented with severe tricuspid bioprosthetic regurgitation (patient 24, Table 1).

Table 2. Aortic Valve-in-Valve Implantation: Valve Characteristics at Baseline and After the Procedure

Patient	Failed Aortic Valve Type	Failed Valve Size, mm	Failure Mode	Implanted Valve Size, mm	Access Site	Baseline Mean Gradient, mm Hg	Final Mean Gradient, mm Hg	Baseline Area, cm ²	Final Area, cm ²	Baseline Regurgitant Grade	Final Regurgitant Grade
8	Carpentier-Edwards	25	S & R	23	TF/TA	28	11*	1.3	2.0	4	0
9	Carpentier-Edwards	23	S & R	23	TA	31	24	0.7	1.0	4	0
10	Carpentier-Edwards	23	S	23	TA	62	27	0.6	0.9	1	0
11	Ionescu Shiley	21	S	23	TA	40	23	0.8	0.9	1	0
12	Carpentier-Edwards	25	S	26	TA	30	13	0.6	N/A	1	0
13	Carpentier-Edwards	21	S	23	TA	43	24	0.3	0.9	4	1
14	Shelhigh Superstentless	21	S	23	TA	54	16	0.4	1.1	2	0
15	Medtronic Freestyle	21	R	23	TA	8	11	N/A	N/A	4	0
16	Medtronic Mosaic	21	S & R	23	TA	37	30	0.8	0.9	4	0
17	Carpentier-Edwards	23	S & R	23	TF	20	20	1.1	1.1	4	1

S indicates stenosis; R, regurgitation; TA, transapical; and TF, transfemoral.

*Subsequent rise in gradient; see main text.

Right heart catheterization suggested that coaxial positioning within the failed tricuspid prosthesis could not be accomplished percutaneously. A right intercostal surgical approach with direct right atrial puncture was used to facilitate coaxial positioning (Figure 3). Although the transvalvular gradient was low, there was excessive cardiac motion. Accordingly, rapid ventricular pacing was used to reduce cardiac motion during successful THV deployment. The patient was clinically improved at a follow-up of 260 days (Table 4).

Procedural Outcomes

There were no intraprocedural deaths (Table 4). Mortality at 30 days was 4.2% (1 patient), caused by multisystem failure after cardiac surgery. Mortality was 0% at 30 days in patients with failed aortic surgical prostheses, 14% (1 patient) for mitral prostheses, 0% for tricuspid prostheses, and 0% for pulmonary prostheses. For the group as a whole, device success was 98.6% and procedural success was 98.6%. At the 30-day follow-up, the incidence of clinical stroke was 4.2% (1 patient). No patient developed new heart block requiring a new permanent pacemaker. Median hospital stay was 8 days (interquartile range, 4 to 12 days).

Valve Function

Valve function was assessed by transthoracic echocardiography at baseline and before hospital discharge. Aortic valve-in-valve implantation (n=10) was associated with a reduction in mean

transaortic gradient from 35.3 ± 15.7 to 20.2 ± 6.7 mm Hg ($P < 0.01$) with an increase in area from 0.73 ± 0.32 to 1.10 ± 0.40 cm² ($P = 0.01$; Table 2). In 4 patients with severe bioprosthetic valvular regurgitation, this was decreased to none or trivial. Mitral valve-in-valve implantation (n=7) was associated with a reduction in mean gradient from 12.9 ± 5.4 to 8.0 ± 1.3 mm Hg ($P = 0.29$), an increase in area from 0.7 ± 0.4 to 1.7 ± 0.4 cm² ($P = 0.20$), and a reduction in regurgitation grade from severe (n=5) to none or trivial (n=4). Pulmonary valve implantation (n=6) was associated with a reduction in mean gradient from 36.0 ± 15.3 to 20.7 ± 20.0 mm Hg ($P = 0.10$) and no detectable regurgitation in any patient. Tricuspid valve implantation (n=1) was associated with a reduction in mean transvalvular gradient from 11 to 4 mm Hg and a reduction in regurgitation from severe to trivial.

Regurgitation was assessed by TEE at the time of implantation as valvular, paravalvular (between the native valve and the original failed prosthetic valve), or intervalvular (between the original "outer" valve and the new "inner" transcatheter valve). No patient had more than trivial valvular or intervalvular regurgitation after successful valve-in-valve implantation.

Follow-Up

At the last clinical follow-up (median, 135 days; interquartile range, 46 to 254 days), there were no additional strokes, myocardial infarcts, major bleeds, repeat valve interventions, or deaths (Table 4). New York Heart Association (NYHA) class

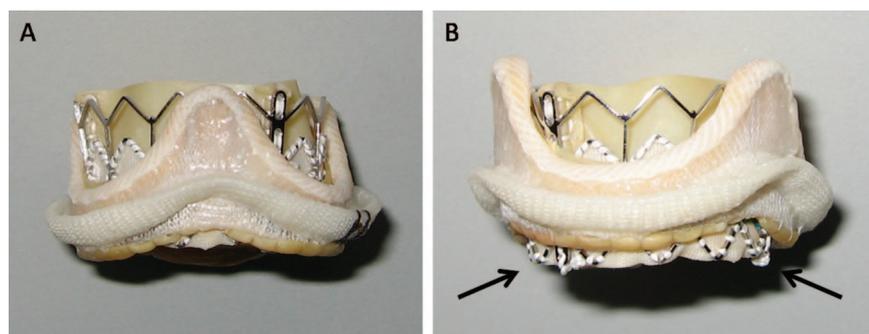


Figure 4. Transcatheter valve deployed within a surgical prosthesis (SAPIEN THV and Carpentier-Edwards). A, Incorrect positioning. The outflows of the surgical prosthesis and THV are superimposed. During balloon deployment, the prosthetic struts may be splayed, allowing the THV to embolize (as in Figure 5). B, Correct positioning. The THV overlaps the sewing ring of the surgical prosthesis, allowing for more secure fixation.

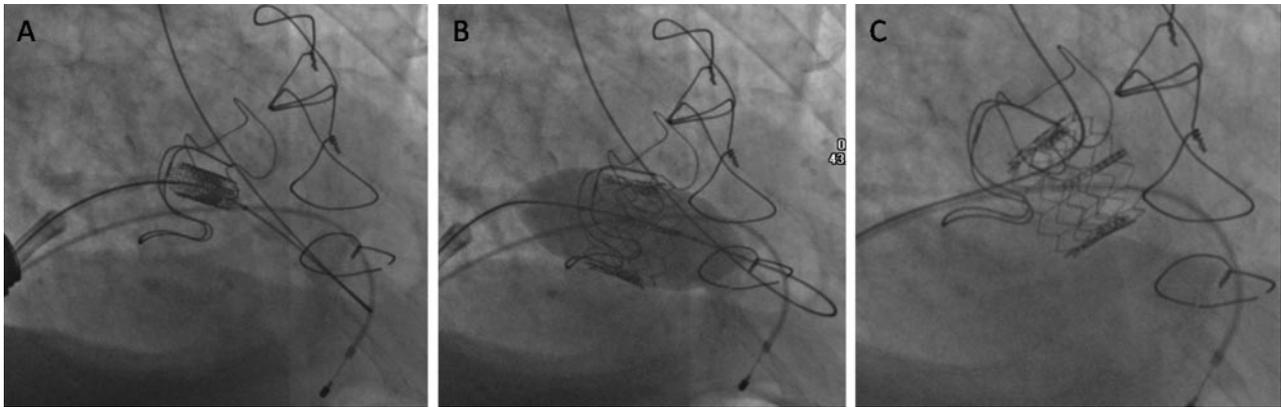


Figure 5. First-in-human attempted mitral valve-in-valve procedure. A, Through the use of a transvenous, transeptal approach, a balloon-expandable THV has been positioned within a degenerated mitral bioprosthesis. The radiolucent sewing ring is not visible and is not overlapped by the THV. B, The balloon is inflated, splaying the struts of the prosthesis and resulting in ejection of the THV. C, The THV was maintained in a stable position by the coaxial guidewire. The patient (patient 1) underwent conventional surgery.

improved so that at baseline 88% of patients were in NYHA class III or IV and at last follow-up 88% of patients were in NYHA class I or II (Figure 8). Late structural valve failure¹⁴ or embolization did not occur. A significant increase in gradient during follow-up was noted in 1 patient who had originally presented with a stenotic and regurgitant aortic surgical bioprosthesis (patient 8). The echocardiographic mean gradient fell from 28 to 11 mm Hg immediately after THV implantation but rose to 29 mm Hg at 1 month. This appeared to be due possibly to a strut from the original surgical valve protruding into the outflow portion of the THV. Despite this, the patient remained clinically improved and well with unchanged valve function at the 3-year follow-up.

Discussion

Preclinical Studies

In vitro and in vivo animal testing has demonstrated the feasibility of aortic valve-in-valve implantation, with acceptable

hemodynamic function, minimal paravalvular regurgitation, and midterm durability. However, such studies have provided only preliminary data, and even preliminary data are largely unavailable.^{5,6} It is unlikely that we will see rigorous testing of all potential combinations of available surgical and transcatheter valve types, frames configurations, and sizes. With such little information available, it is particularly desirable for clinical experience to be documented and disseminated.

Pulmonary Procedure

The majority of prior valve-in-valve experience has been with surgically implanted right heart conduits incorporating xenograft or homograft valves. Pulmonary conduits are tubular, low-pressure structures that in many ways are ideally suited to THV implantation. Patients have frequently undergone multiple prior procedures; consequently, the threshold for reoperation is very high. Prior experience has demonstrated sustained benefit with both the Melody (Medtronic Inc,

Table 3. Mitral Valve-in-Valve Implantation: Valve Characteristics at Baseline and After the Procedure

Patient	Failed Valve	Failed Valve Size, mm	Failure Mode	Access	THV, mm	Baseline Mean Gradient, mm Hg	Final Mean Gradient, mm Hg	Baseline PHT, ms	Final PHT, ms	Baseline Regurgitant Grade	Final Regurgitant Grade
1	Edwards SAV (model 6650)	29	R	Venous	26	6	N/A	N/A	N/A	4	N/A
2	Baxter Edwards (model 6900P)	25	S	Atrial & apical	26	17	6	328	117	1	N/A
3	Edwards SAV (model 6650)	27	R	Apical	26	8	9	N/A	N/A	4	0
4	Edwards SAV (model 6650)	27	R	Apical	26	10	9	93	105	4	0
5	Medtronic Mosaic (model 310)	25	S	Apical	26	18	9	301	183	1	1
6	Edwards SAV (model 6650)	27	R	Apical	23	11	8	130	121	4	1*
7	Medtronic Intact (model 705)	27	R & S	Apical	23	20	7	198	164	4	1†

PHT indicates pressure half-time; R, regurgitation; and S, stenosis.

*Paravalvular between the failed bioprosthesis and the THV.

†Paravalvular between the failed bioprosthesis and native annulus.

Table 4. Major Adverse Outcomes at 30 Days and at Last Follow-Up (Median, 135 Days) in 24 Patients

Adverse Outcome	At 30 Days, n (%)	At Last Follow-Up, n (%)
MACCE	1 (4.2)*	2 (8.3)
Death	1 (4.2)	2 (8.3)
Stroke	1 (4.2)	1 (4.2)
Renal failure	1 (4.2)	1 (4.2)
Myocardial infarction	0 (0)	0 (0)
Major bleeding	1 (4.2)	1 (4.2)
Permanent pacemaker	0 (0)	0 (0)

Major adverse cardiac and cerebrovascular events (MACCE) included death, myocardial infarction, stroke, or renal failure.

*One patient suffered a stroke and renal failure and died.

Irvine, Calif)^{15,16} and SAPIEN valves.¹⁷ However, aortic, mitral, and tricuspid valve-in-valve procedures present more challenging access, anatomic, durability, and hemodynamic considerations.

Aortic Procedure

There have been a few isolated reports of valve-in-valve implantation within failed surgical aortic bioprostheses. Wenawesser et al⁷ implanted a CoreValve THV (Medtronic Inc) within an aortic Mitroflow surgical valve (Carbomedics Inc, Austin, Tex) using a transarterial approach with excellent functional outcome at 1 year. Similarly, there have been isolated case reports with short-term follow-up of SAPIEN

valve implantation within stented^{8,18} and stentless surgically implanted aortic valves.¹⁹ We extend this experience with 10 high-risk patients in whom THV implantation was uniformly successful with excellent improvement in valve function, no major morbidity, and no 30-day mortality.

New atrioventricular block may develop after aortic valve replacement surgery and with transcatheter aortic valve implantation in patients with native aortic valve disease. It is noteworthy that no patient in this series developed heart block requiring a new permanent pacemaker.^{20,21} Presumably, the rigid bioprosthetic sewing ring and valve frame protect the septal conduction tissues from injury at the time of THV implantation. This may suggest a reduced need for temporary pacing electrodes and prolonged ECG monitoring compared with THV implantation in native aortic valve stenosis. Coronary ostial obstruction by a displaced native aortic leaflet may rarely occur with THV implantation in the setting of native valve aortic stenosis.²² Whether coronary obstruction might also occur with valve-in-valve implantation in the aortic position is not known.

Mitral Procedure

A first-in-human transvenous attempt was unsuccessful because of an inability to align the THV coaxially within the prosthetic valve. A second attempt using the transatrial approach, previously described in an ovine model,²³ was also unsuccessful because of an inability to position the THV coaxially within the bioprosthesis. All 5 subsequent high-risk mitral procedures were transapical, successful, and without

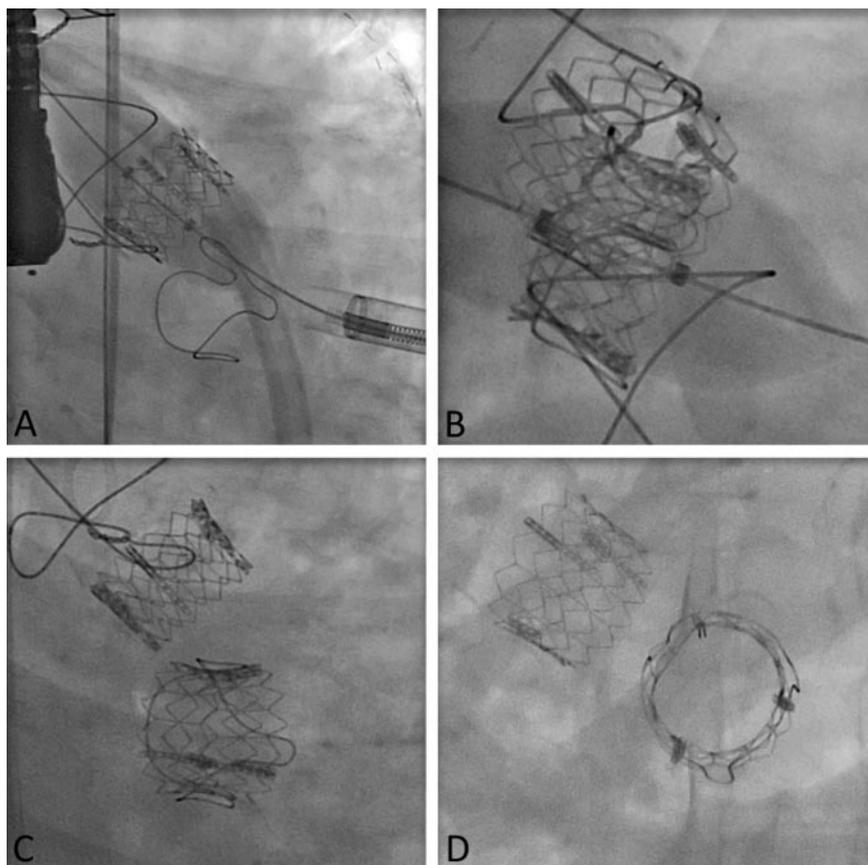


Figure 6. A, Transapical implantation of a balloon-expandable THV in a patient with stenosis of the native aortic valve. B, A second THV is implanted within a regurgitant mitral surgical prosthesis. C, Right anterior oblique view. D, Left anterior oblique view. Patient 3.

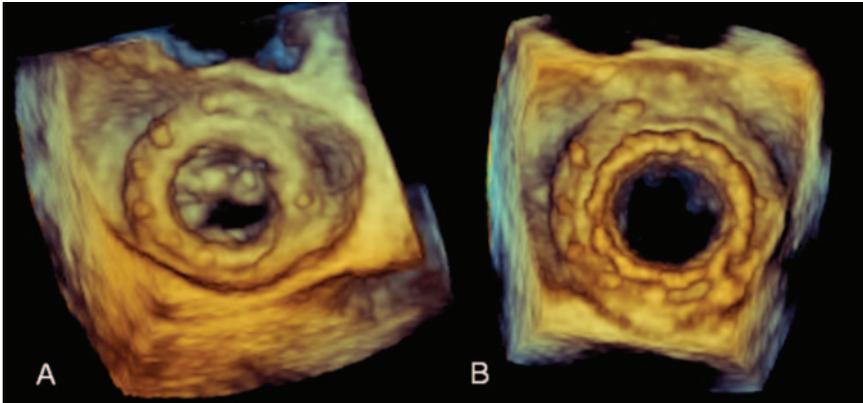


Figure 7. A, A 3-dimensional TEE image of a surgically implanted bioprosthetic mitral valve en face from the left atrium in diastole. The sewing ring with suture pledgets and thickened, stenotic leaflets is visible. B, The frame of a transcatheter valve can be seen within the sewing ring of the failed prosthesis. The leaflets are wide-open in diastole. Patient 7.

mortality. The apical approach has the advantage of providing direct, coaxial, and reproducible access to the mitral valve.⁹ Currently, this may be the mitral access route of choice for balloon-expandable THV implantation (Movies II and III of the online-only Data Supplement).

Mitral valve-in-valve implantation was associated with a reduction in mean gradient from 12.9 to 8.0 mm Hg and an increase in area from 0.7 to 1.7 cm². Although not statistically significant, gradient decreased or remained essentially unchanged in all patients. In the 3 patients with severe stenosis as a major failure mode (Table 3), mean gradient fell from 18.3 to 7.3 mm Hg. In 5 of 7 patients with mitral regurgitation as a major failure mode, none had more than mild postprocedural regurgitation.

Positioning

Preclinical studies suggested that the balloon-expandable THV should be positioned so that its outflow was aligned

with the outflow of the surgical bioprosthesis. However, our initial case demonstrated the possibility of displacement of the surgical valve posts during deployment. Subsequent experience has shown the importance of THV fixation within the annular sewing ring of surgical prostheses. It is important that the balloon-expandable THV be as coaxial as possible within the failed prosthesis at the time of deployment. Angiographic imaging should be in a plane perpendicular to the prosthesis to minimize foreshortening. Movement during deployment should be minimized with rapid ventricular pacing. Further modifications of the THV and delivery system may be desirable to improve the ease and accuracy of implantation.

Valve Function

Currently available THVs appear to have hemodynamic properties comparable to those of the best surgical biopros-

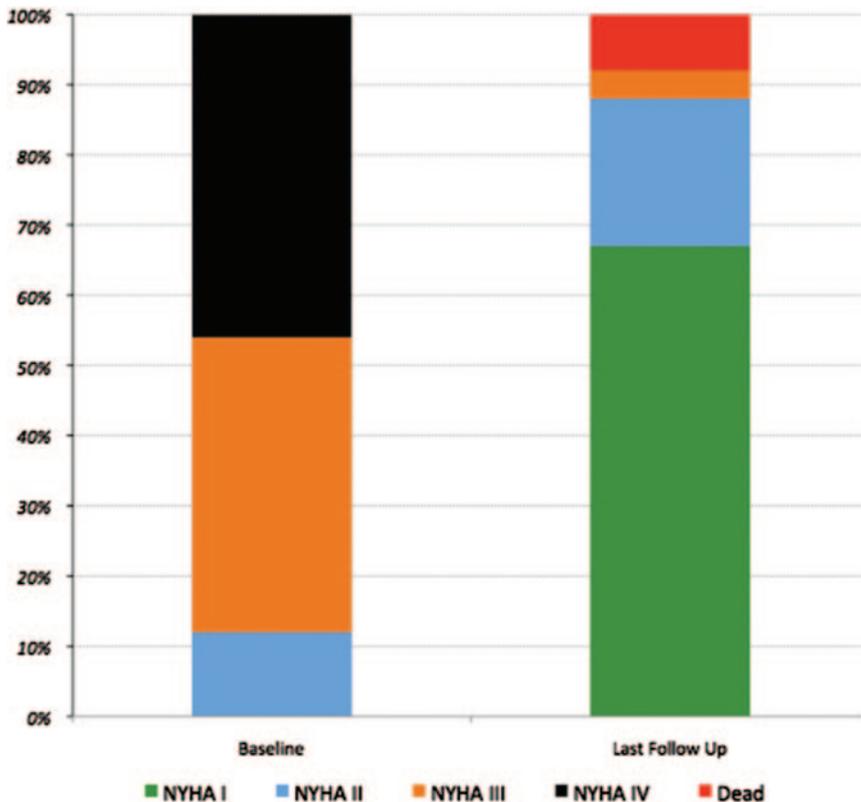


Figure 8. Change in NYHA functional class.

theses.^{24–26} Accelerated wear testing and midterm clinical data suggest that durability is sufficient to achieve meaningful clinical benefit in high-risk patients with native aortic valve stenosis.^{26,27} It might be anticipated that the durability of THVs will be reduced when they are underexpanded, as is generally the case when current THVs are implanted within current surgical bioprostheses.

THVs constrained within smaller surgical bioprostheses can be expected to have higher transvalvular gradients and lower effective orifice areas than when relatively fully expanded in a native annulus. Fortunately, valvular regurgitation was absent or trivial after THV implantation. Although paravalvular leaks are common after THV implantation within a native aortic valve, the relatively symmetrical sewing ring of surgical bioprostheses appeared to facilitate valve-in-valve sealing. In this limited experience, the asymmetrical scalloped sewing ring of some surgical prostheses did not result in suboptimal sealing. No patient was left with more than a mild leak between the THV and bioprosthesis, and the trivial regurgitation seen did not appear to have clinical consequences.

Sizing Considerations

Prosthetic heart valves are typically described according to their external diameter. However, it is the internal diameter of a failed valve that is relevant for valve-in-valve implantation. Internal diameter varies by manufacturer, model, and size. Although manufacturers may report internal diameter, nomenclature is far from standardized and may be misleading.^{28,29} Moreover, calcified, bulky, or torn tissue leaflets, pannus, and variations in valve design have unpredictable implications. In the future, imaging modalities such as TEE and computed tomography may prove helpful in sizing (Figures 1 and 6).

Optimal THV function requires expansion of the prosthesis to its nominal dimensions. A THV implanted within a smaller surgical prosthesis can be expected to function suboptimally with increased transvalvular gradient, impaired leaflet coaptation, and reduced durability. The acceptable boundaries of underexpansion are undefined. Residual stenosis and limited durability may be acceptable in some patients with no alternatives but unacceptable in others. For example, the smallest currently available 23-mm SAPIEN THV appears to result in acceptable hemodynamic performance when implanted within a 23-mm bioprosthetic surgical valve with an internal diameter of 19 mm. However, implantation of this THV within a 21-mm surgical valve can be anticipated to result in a significant residual gradient, whereas implantation within a 19-mm prosthesis might result in severe stenosis. The potential for valve-in-valve therapy for late bioprosthetic failure may arguably be an additional reason for maximizing the size of an initial surgical or transcatheter valve. Newer THVs with smaller and larger diameters are becoming available and will likely extend the range of surgical bioprostheses amenable to valve-in-valve therapy.

Conclusions

Transcatheter valve-in-valve implantation is a reproducible option for the management of selected patients with biopros-

thetic valve failure. Aortic, pulmonary, mitral, and tricuspid tissue valves may be amenable to this approach. This finding may have important implications with regard to valve replacement in patients at prohibitive risk with conventional surgery.

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Disclosures

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CLINICAL PERSPECTIVE

The majority of prosthetic heart valves currently implanted are tissue valves that can be expected to degenerate with time and eventually fail. Repeat cardiac surgery to replace these valves is associated with significant morbidity and mortality. Transcatheter heart valve implantation within a failed bioprosthesis, a “valve-in-valve” procedure, may offer a less invasive alternative. Valve-in-valve implantations were performed in 24 high-risk patients. Failed valves were aortic (n=10), mitral (n=7), pulmonary (n=6), or tricuspid (n=1) bioprostheses. Implantation was successful with immediate restoration of satisfactory valve function in all but 1 patient. No patient had more than mild regurgitation after implantation. No patients died during the procedure. Thirty-day mortality was 4.2%. Mortality was related primarily to learning-curve issues early in this high-risk experience. New York Heart Association functional class improved in most patients. At a median follow-up of 135 days and a maximum follow-up of 1045 days, 91.7% of patients remained alive with satisfactory valve function. Transcatheter valve-in-valve implantation is a reproducible option for the management of bioprosthetic valve failure. Aortic, pulmonary, mitral, and tricuspid tissue valves were amenable to this approach. This finding may have important implications with regard to valve replacement in high-risk patients.

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Transcatheter Valve-in-Valve Implantation for Failed Bioprosthetic Heart Valves
John G. Webb, David A. Wood, Jian Ye, Ronen Gurvitch, Jean-Bernard Masson, Josep Rodés-Cabau, Mark Osten, Eric Horlick, O. Wendler, Eric Dumont, Ronald G. Carere, Namal Wijesinghe, Fabian Nietlispach, Mark Johnson, Christopher R. Thompson, Robert Moss, Jonathon Leipsic, Brad Munt, Samuel V. Lichtenstein and Anson Cheung

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