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VALVULAR HEART DISEASE (V NKOMO, SECTION EDITOR)

Transcatheter Valve-in-Valve Therapies: Patient Selection, Prosthesis Assessment and Selection, Results, and Future Directions

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Abstract The development of transcatheter valve implantations (TAVI) has induced profound changes in the treatment of valvular heart disease over the past decade. At the same time, due to excellent clinical results, bioprostheses continuously outperformed mechanical prostheses. The increasing number of elderly patients has led to numerous patients presenting with deteriorated bioprostheses needing reoperation. In selected high-risk patients or patients with unreasonable surgical risk, valve-in-valve TAVI has advanced to a viable alternative to conventional redo surgery. High procedural success, good hemodynamics and acceptable clinical results were reported up until now. Valve-in-valve TAVI seems to be safe and effective in treatment of deteriorated valve prostheses in high-risk patients. The valve-in-valve concept presents the next step toward an individual treatment strategy for patients at prohibitive risk for conventional surgery. Present studies were reviewed with special concern to patient selection, prosthesis assessment, device selection, clinical outcome and technical challenging aspects as well.

Keywords TAVI · Valve-in-valve · Aortic · Mitral · Transcatheter · Valvular heart disease

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Introduction

The development of transcatheter heart valve procedures has led to profound changes in the treatment of valvular heart disease in high risk patients [1•]. Since the first description of transcatheter aortic valve implantation (TAVI) by Cribier in 2002, TAVI has advanced to an essential tool for everyday practice in most cardiosurgical centers [1•, 2].

Meanwhile, conventional valve surgery also underwent significant changes. Excellent long-term results with more than 20-years of experience, reducing thromboembolic risk and avoiding anticoagulation are strong arguments for conventionally implanted biologic prostheses [3]. Thus, bioprostheses continuously outperformed mechanical valves, even in younger patients [4]. Unsurprisingly, the relative use of biologic substitutes increased up to 80 % [5•]. Contemporary surgical valve therapy faces an increasing amount of patients, requiring redo-valve procedures due to deteriorated biologic substitutes [4]. However, redo-procedures, especially in high-risk patients, are still associated with a perioperative risk up to 20 % [3, 6, 7].

Walther et al. described the "valve-in-valve"-concept in 2007 and started a new era of surgical and interventional treatment [8, 9]. Since then, multiple series demonstrated safety, feasibility and good clinical results in selected high-risk patients requiring redo-aortic valve surgery [10••, 11]. The application spectrum was then pushed further by Kempfert in 2008, who reported a valve-in-valve procedure for mitral valve bioprosthesis in a sheep [12]. Not that much later, in 2009, Cheung and colleagues first performed a mitral-valve-in-valve procedure in a human [13]. Since that time, several groups demonstrated successfully valve-in-valve procedures for deteriorated mitral valve bioprostheses and even for mitral annuloplasty rings [1•, 14–16].

Today, the valve-in-valve concept has advanced to a viable treatment strategy in patients with high surgical risk.

Valve-in-valve TAVI has successfully been performed in aortic, mitral, pulmonic and tricuspid position, using various percutaneous or minimally invasive surgical approaches [3]. The aim of this article was to illuminate technical aspects, challenges and future perspectives of this promising evolving approach.

Patient Selection

Selection of the right procedure for the right patient is perhaps one of the most demanding aspects in surgery. Patients deemed to be TAVI-candidates are usually at unreasonably high risk for conventional surgery. Elderly patients with a broad spectrum of concomitant comorbidities are the ones that we are most concerned about [10••].

To date, official, guideline-based indications for TAVI are still not available and the decision for TAVI is often based on inaccurate, less objective and rather subjective definition of "high" risk. A well defined risk assessment for reproducibly distinguishing "high" and "prohibitive" risk is mandatory [11]. Established scores for risk evaluation of patients undergoing cardiac surgery are the Society of Thoracic Surgeons (STS, http://riskcalc.sts.org)- Score and the European System for Cardiac Operative Risk Evaluation (EuroSCORE). An overestimation of perioperative risk in high risk and especially valve patients, by EuroSCORE, is well-described [17]. Hence, scoring systems must carefully be used and interpreted [11]. The single use of scoring systems to identify TAVI-candidates might be inaccurate [11]. Although, a revised version of the EuroSCORE, the EuroSCORE II (www.euroscore.org), is available since November 2011, its broad clinical implementation and evaluation in TAVI-patients has not yet been achieved.

With regards to the deficiencies of present scoring systems, a sophisticated clinical assessment by experienced physicians gains strong importance [11]. However, there seems to be broad agreement that the decision-making process needs to be performed by an interdisciplinary expert team, consisting of cardiologists and cardiac surgeons [11, 18•, 19]. In the best-case scenario an anesthesiologist and a critical care physician is added to the expert forum [1•].

Despite missing clear guideline-based indications, most study groups agreed upon a limited number of criteria for choosing TAVI. An STS-Score >10 %, a logistic EuroSCORE >20 % or an additive EuroSCORE ≥9 are frequently reported thresholds to screen TAVI-candidates [10••, 11, 18•, 19]. Further reported indications for catheter-based valve procedures are previous cardiac surgery or concrete contraindications for conventional surgery like presence of porcelain aorta [10••, 20, 21]. However, "soft" factors like general frailty or prior chest radiation are mixed within the heterogeneity of contraindications and serve as suitable for TAVI [10••, 20, 21]. The threshold for age varies between 75 and 80 years [11, 18•]. Particularly, patients with deteriorated tissue valves are supposed to benefit from beating-heart TAVI, avoiding potentially adverse effects of extracorporal circulation and inherent risks of complex redo surgery [10••, 11].

Prosthesis Assessment, Sizing and Selection of Transcatheter Heart Valve

Bioprostheses are classified to stented and stentless valves and generally include leaflets derived from bovine pericardium or porcine valve leaflets. The radiopaque frame of stented valve virtually demands valve-in-valve therapy. On the other hand of course, stentless valves lack radiopaque markers with no frame to anchor transcatheter heart valves. This is a great challenge for valve-in-valve procedures [3].

Several considerations have to be made, before valve-in-valve TAVI can be performed in suitable patients. Assessment of mechanism of bioprosthetic failure, determination of inner diameter of the prosthetic valve, choosing the right access site and the associated device and determination of the perfect size of the transcatheter heart valve are necessary considerations before performing valve-in-valve TAVI.

The valve-in-valve concept is not the Holy Grail to treat all deteriorated bioprostheses. The presence of endocarditis is a strong contraindication for implantation of a transcatheter heart valve. Due to impracticality to debride infected tissue even the slightest suspicion of an acute or subacute endocarditis needs to be excluded. Recurrence of endocarditis after valve-in-valve TAVI may be fatal. Furthermore, the valve-in-valve procedure is not a sufficient approach for treatment of paravalvular leakage. Treatable, leaflet-related mechanism leading to valve deterioration is degeneration, which includes wear, tear and calcification of the leaflets [3]. Non leaflet-related mechanisms of failure are usually pannus or thrombus formation [3]. In case of a large thrombus formation the risk of embolization should be balanced to the risk of redo surgery.

Determination of the exact internal diameter of the degenerated bioprosthesis plays a key role in valve-in-valve TAVI. Because methodologies for labeling valve sizes are not standardized, the labeled sizes vary by different manufacturers and usually are not associated with the internal diameter of the valve [3, 22, 23]. In addition, the internal diameter of the deteriorated prosthetic valve measured by echocardiography often differs significantly from the internal diameter given by the manufacturer [1•, 11]. Presumably, the reason for this is calcification or pannus formation of the tissue leaflets in most cases [1•]. The sewing ring is the limitation and mainly impedes the expansion of the transcatheter valve and restrictions by calcification or pannus may be eased during expansion, it seems to be justified to rely on the internal diameter given by the manufacturer

rather than on the diameter measured by echocardiography [1•]. Determination of the internal diameter by computed tomography is only rarely reported and thus appears to be irrelevant in valve-in-valve TAVI.

Determination of the right size of the transcatheter heart valve crucially depends on the exact diameter of the implanted bioprosthesis. Usually, the transcatheter valve is chosen with an external diameter matching or exceeding the determined internal diameter of the deteriorated bioprosthesis [1•, 3]. Most groups oversize the transcatheter valve and this seems to be necessary for secure anchoring and efficient sealing [1•, 3, 4, 11, 14]. Nonetheless, Gurvitch and colleagues mentioned that excessive oversizing may be associated with a significant underexpansion of the transcatheter valve resulting in impaired hemodynamics and durability [3]. Despite lack of reliable boundaries for oversizing clinical experiences suggests that a range of 10 to 30 % may be acceptable [5•]. On the other hand, undersizing of the transcatheter valve may increase the risk for paravalvular leakage, embolization or migration of the valve [5•]. Table 1 summarizes labeled sizes and internal diameters of selected stented bioprosthetic valves. The use of valve-in-valve TAVI in small sized bioprostheses is supposed to be limited by the relevant underexpansion of the transcatheter heart valve [5•]. Azadani and colleagues performed several experimental series in small sized Carpentier-Edwards Perimount prostheses at sizes 19, 21 and 23 mm [25]. In all cases full expansion of the transcatheter heart valve was impeded by the sewing ring. Only the 23 mm prosthesis allows acceptable hemodynamic results [25]. Azadani summarized that patients with 19 and 21 mm Carpentier-Edwards Perimount bioprostheses may be poor candidates for valve-in-valve TAVI [25]. Nonetheless, there is clinical experience with valve-in-valve TAVI in small sized degenerated bioprostheses and reported improvement in NYHA-functional class [11]. The individual specifications of the degenerated bioprostheses including effective orifice area and internal diameter given by the manufacturer should carefully be taken into consideration in each single case.

Three transcatheter heart valve devices are currently reported in the setting of valve-in-valve TAVI:

1. Most experiences exist with the Edwards SAPIEN® valve (Edwards Lifesciences). The SAPIEN® valve is a balloon expandable valve with bovine pericardial leaflets mounted on a stainless steel frame. The current SAPIEN XT® valve is characterized by a low profile and a cobalt chromium frame [24]. Available sizes are 20, 23, 26 and 29 mm. The SAPIEN® valve can reversely be crimped and thus used for either transapical or transarterial approaches. A 23 mm SAPIEN® (Edwards Lifesciences) valve would be suitable for degenerated bioprostheses with an internal diameter of 18 to 21.5 mm [11]. For diameter range of 21.5 to 24.5 mm a 26 mm Edwards SAPIEN® (Edwards Lifesciences) and for internal diameters larger than 24.5 mm, a 29 mm Edwards SAPIEN® (Edwards Lifesciences) valve is convenient [11].
2. The CoreValve® (Medtronic Inc.) consists of porcine pericardial leaflets that are mounted on a self-expanding nitinol frame. Retraction of the delivery-sheath induces the deployment of the valve. The CoreValve® can only be delivered and positioned in one direction and thus is only usable for a retrograde transarterial approach. Available

Table 1 Internal diameter of selected stented bioprostheses

Labeled size	Valve model	Manufacturer	Internal diameter (stent, mm)
18	Soprano	Sorin Group	17.8
19	Hancock Ultra	Medtronic	17.5
	Mosaic	Medtronic	17.5
	Perimount	Edwards Lifesciences	18
	Magna	Edwards Lifesciences	18
	Mitroflow	Sorin Group	15.4
20	Soprano	Sorin Group	19.8
21	Hancock Ultra	Medtronic	18.5
	Mosaic	Medtronic	18.5
	Perimount	Edwards Lifesciences	20
	Magna	Edwards Lifesciences	20
	Mitroflow	Sorin Group	17.3
22	Soprano	Sorin Group	21.7
23	Hancock Ultra	Medtronic	22
	Mosaic	Medtronic	20.5
	Perimount	Edwards Lifesciences	22
	Magna	Edwards Lifesciences	22
	Mitroflow	Sorin Group	19
24	Soprano	Sorin Group	23.7
25	Hancock Ultra	Medtronic	22.5
	Mosaic	Medtronic	20.5
	Perimount	Edwards Lifesciences	22
	Magna	Edwards Lifesciences	22
	Mitroflow	Sorin Group	21
26	Soprano	Sorin Group	25.6
27	Hancock Ultra	Medtronic	24
	Mosaic	Medtronic	24
	Perimount	Edwards Lifesciences	26
	Magna	Edwards Lifesciences	26
	Mitroflow	Sorin Group	22.9
28	Soprano	Sorin Group	27.6
29	Hancock Ultra	Medtronic	26
	Mosaic	Medtronic	26
	Perimount	Edwards Lifesciences	28
	Magna	Edwards Lifesciences	28

No responsibility is taken for the correctness of this information

sizes are currently 26, 29 and 31 mm. The use in the valve-in-valve concept is limited by the long frame of the CoreValve® [3]. The size of the CoreValve® is estimated by the manufacturer's sizing principles for aortic annuli. A 26 mm CoreValve® for 20 to 23 mm, a 29 mm CoreValve® for 23 to 27 mm and a 31 mm CoreValve® for 26 to 31 mm internal diameter seem to be suitable [5•].

3. The Melody® valve (Medtronic Inc.) consists of a bovine jugular venous valve on a platinum iridium scaffold. The valve is delivered by a balloon-in-balloon system. Fields of application are treatment of dysfunctional right ventricular outflow tract or pulmonary bioprostheses in patients with congenital heart diseases [3].
4. The use of other devices like the JenaValve® (JenaValve Technology GmbH, Munich, Germany) or the Acurate TA® (Symetis, Ecublens, Switzerland) has not yet been reported.

A variety of access routes can be considered depending on the position of the deteriorated valve. Many work groups advocate a "transfemoral-first" policy in TAVI-procedures [5•, 19]. Nonetheless, most experiences in valve-in-valve TAVI are reported with the transapical approach, which allows direct and coaxial access to aortic and mitral valve. The transapical approach facilitates the crossing of a stenotic bioprosthesis, but is associated with a thoracotomy and of course general anesthesia. The transfemoral access might also be challenging or even risky in the presence of strong calcifications of the aortic arch or elongation of the femoral arteries. Valve-in-valve therapies of the pulmonary or tricuspid valve are usually performed via a transjugular approach.

Valve-in-Valve Therapy in Aortic Position

Transapical and transarterial approaches using the Edwards SAPIEN® or Medtronic CoreValve® have been frequently reported [3, 5•, 11, 26]. The use of the Medtronic Melody® valve in aortic position was reported by Hasan et al. [27]. There are no present experiences with valve-in-valve TAVI utilizing the Melody® valve in aortic position. Despite promising short time results, the durability of a venous valve in systemic circulation remains doubtful [3, 27].

Valve-in-Valve and Valve-in-Ring Therapy in Mitral Position

In 2007 Cheung and colleagues attempted a transatrial approach for mitral valve-in-valve TAVI and failed. The proper alignment of the delivering system was extremely difficult [15]. Later on they converted to transapical approach and firstly performed a transapical mitral valve-in-valve TAVI [13, 15]. They advocated the transapical access to be ideal for mitral valve-in-valve TAVI, providing direct and coaxial access [1•, 15]. Since then, several groups reported successful valve-in-valve TAVI in mitral position [1•, 14, 15]. Kempfert and colleagues demonstrated successful transapical valve-in-ring TAVI in 2009 [28]. The Edwards SAPIEN® is the only valve that has been used for valve-in-valve procedures in mitral position so far [3]. Due to its design the CoreValve® system is not suitable for valve-in-valve in mitral position [5•]. The Medtronic Melody® valve has been used in a sheep model for mitral valve-in-ring TAVI [29•]. In 2012, Michelena and colleagues published the first successful antegrade valve-in-vale implantation of a Medtronic Melody® valve in mitral position in an 85 year old patient using a transvenous femoral access [46].

Valve-in-Valve Therapy in Tricuspid Position

The successful use of the Edwards SAPIEN® and the Medtronic Melody® valve for valve-in-valve TAVI in a tricuspid position is described [3, 30–32]. Both valves are delivered and positioned via a transjugular approach [30, 31]. No procedural difficulties were mentioned [30–32].

Valve-in-Valve Therapy in Pulmonary Position

For pulmonary valve-in-valve TAVI the Medtronic Melody® valve and the Edwards SAPIEN® valve were used [27, 33]. The need for pulmonary valve-in-valve therapies is often associated with congenital heart disease in patients who have undergone multiple previous procedures and thus are ideal candidates for catheter-based therapies [3].

Valve-in-Valve Therapy for Stentless Bioprostheses

Kapetanakis reported first successful valve-in-valve TAVI for a deteriorated stentless bioprostheses in a transapical approach in 2011 [34]. In the same year Bagur et al. described a successful procedure via a transfemoral access [35]. A retrospective analysis that compares redo aortic root replacement and valve-in-valve TAVI presented comparable clinical results in both groups [36]. Nevertheless, valve-in-valve TAVI for stentless bioprostheses is associated with several technical challenging aspects. Firstly, orthograde positioning of the transcatheter valve may be complicated by the lack of radiopaque markers. Secondly, in some stentless substitutes like Medtronic Freestyle® there is a close proximity between valve level and coronary arteries. In those cases, a low-profile transcatheter valve like the Edwards SAPIEN XT® might be better suited than Medtronic CoreValve®. Thirdly, the missing protective frame of the stentless bioprosthesis is of technical concern. The stent frame ensures that valve tissue will not be displaced during expansion of the transcatheter valve. In the case of stentless valves or externally mounted leaflets (e.g., Mitroflow® valve; Sorin Group) this potentially life-saving protection is absent.

Valve-in-Valve for Concomitant Procedures

Valve-in-valve TAVI has not only been performed as a single-valve procedure. For example Seiffert et al. reported successful simultaneous valve-in-valve TAVI in aortic and mitral position during one procedure [37]. Jux et al. described successful simultaneous valve-in-valve implantation of two Medtronic Melody® valves in a tetralogy of Fallot-patient with history of prior tricuspid valve replacement and pulmonary homograft implantation [31].

Technical Aspects of Positioning and Deployment

For optimal positioning of the transcatheter valve a coaxial adjustment within the degenerated bioprosthesis is mandatory. Usually radiopaque markers of the bioprosthesis indicate the landing zone very clearly. For this purpose, the x-ray equipment should be aligned perpendicularly to the valve plane (Fig. 1). In most cases a left anterior oblique-cranial alignment provides good view in the case of aortic bioprosthesis [3]. For mitral valve procedures right anterior oblique views might be helpful [3]. For secure anchoring, the transcatheter valve should overlap the sewing ring of the degenerated bioprosthesis. For optimal procedure outcome it is mandatory to know exact characteristics of the degenerated bioprosthesis, including radiologic appearance, diameters and frame design. In case of radiolucent valves, like stentless valves, a pigtail catheter placed in one of the aortic cusps and echocardiographic guidance may be required for optimal positioning of the transcatheter valve [3].

The use of prior balloon valvuloplasty is conducted differently by several groups [1•, 3, 4, 11]. Prior valvuloplasty may facilitate crossing of the deteriorated bioprosthesis and positioning of the transcatheter valve, but carries an inherent risk of additional embolization [3]. Additionally, leaflet tears can cause severe hemodynamic instability if the implantation of the transcatheter valve is delayed for any reasons [3]. Usually, prior valvuloplasty is more frequently demanded in transarterial, but not generally necessary in transapical approaches or in severely regurgitatant bioprostheses [3]. The funneled inflow and leaflet-opening facilitates the crossing of the bioprosthesis in the transapical approach [3].

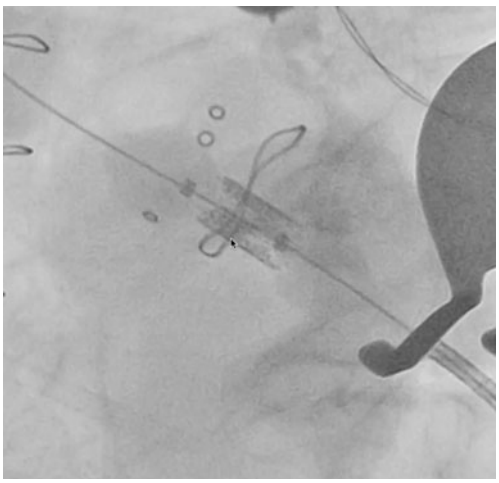

Fig. 1 Orthograde positioning of the transcatheter valve (Edwards SAPIEN)

Rapid pacing on hand is generally recommended for the Edwards SAPIEN® valve but not necessary for deployment of the Medtronic CoreValve®. Rapid pacing is not mandatory for implantation of the Medtronic Melody® valve in pulmonary or tricuspid position. It is uncertain whether or not rapid pacing is generally needed for deployment of the SAPIEN® valve in a low pressure system [3].

Results

Medline-indexed studies were reviewed and a total of 71 cases for aortic, 27 for mitral, 16 for tricuspid and 124 for pulmonic valve-in-valve TAVI were analyzed (Table 2). Additionally, we reviewed the "Global Valve in Valve Registry" (www.valveinvalve.com; [44•]), which collected data on a total of 420 patients undergoing valve in valve TAVI in 54 centers in Europe, North-America, Australia, New Zealand and the Middle East. Those were presented at EuroPCR 2012 by Danny Dvir on behalf of the "Global Valve-in-Valve Registry"-investigators and are not yet published. All reviewed studies included high-risk patients with a logistic EuroSCORE ranging from 27±13 % to 58.0±7.0 % [1•, 41]. Most experience exists with the Edwards SAPIEN® valve in aortic (n=63/71) and mitral position (n=27/27). For tricuspid and pulmonic position the Medtronic Melody® valve is mostly used (Table 2). All studies reported a significant reduction of transvalvular pressure gradients with a mean postprocedural gradient ranging from 11±4 mmHg to 20.2±6.7 mmHg in aortic and ranging from 5.5±3.6 mmHg to a median of 9 mmHg in mitral position [4, 9, 30, 39]. The valve-in-valve registry confirmed those findings [44•]. A high procedural success, usually 100 %, is described by most groups in all positions [9, 38–40]. Only smaller series reported inferior success rates with 66.7 %, which might be by biased by a small number of reported cases [30, 41]. Additionally, our own results demonstrated TAVI as a short operation with less than 50 minutes procedural time [1•, 11]. TAVI does not require extensive dissections and therefore spares surgical trauma like injury to patent bypasses [1•, 11]. The reviewed studies describe acceptable 30-day results according to the uneventful intraoperative course and excellent hemodynamic results. The reported mortality in those high-risk patients was 5.6 % in aortic and 11.1 % for mitral valve-in-valve patients [1•, 4, 9, 11, 14, 15, 30, 38–40, 41]. The clinical results for valve-in-

Table 2 Selected studies reporting valve-in-valve TAVI

	Year	Number of patients	Mean logistic EuroSCORE	Transcatheter Valve	Procedural success	Mean postoperative transvalvular gradient	30-Mortality
Aortic							
Pasic et al. [38]	2011	14	45.3±22.2 %	Edwards SAPIEN	100.0 %	13.1±6.4 mmHg	14 %
Kempfert et al. [9]	2010	11	32.0±16.0 %	Edwards SAPIEN	100.0 %	11 ±4 mmHg	0 %
Webb et al. [39]	2010	10	31.2±9.0 %	Edwards SAPIEN	100.0 %	20.2 ±6.7 mmHg	0 %
Wilbring et al. [11]	2012	7	52.6±9.0 %	Edwards SAPIEN	100.0 %	19.4 ±4.3 mmHg	0 %
Gotzmann et al. [40]	2010	5	n/a	Medtronic CoreValve	100.0 %	16.4 ±3.6 mmHg	0 %
Seiffert et al. [14]	2010	4	55.8±18.9 %	Edwards SAPIEN	100.0 %	19.0 ±12.4 mmHg	25 %
Piazza et al. [42]	2011	17 3	26.9±12.9 % 13.7±10.1 %	Edwards SAPIEN Medtronic CoreValve	88.0 % 66.7 %	< 20 mmHg < 20 mmHg	10 %
Mitral							
Cheung et al. [15]	2009	11	n/a	Edwards SAPIEN	100.0 %	Median 7 mmHg	0.0 %
Wilbring et al. [1•]	2012	7	58.0±7.0 %	Edwards SAPIEN	100.0 %	5.7±0.8 mmHg	14.3 %
Seiffert et al. [4]	2012	6	33.0±15.0 %	Edwards SAPIEN	100.0 %	5.5±3.6 mmHg	16.7 %
Cerillo et al. [30]	2011	3	37.2±81.5 %	Edwards SAPIEN	66.7 %	Median 9 mmHg	33.3 %
Michelena et al. [46]	2012	1	n/a	Medtronic Melody	100.0 %	n/a	0.0 %
Tricuspid							
Roberts et al. [43]	2011	15	n/a	Medtronic Melody	100.0 %	3.9 mmHg	0.0 %
Cerillo et al. [30]	2011	1	37.2±81.5 %	Edwards SAPIEN	100.0 %	Median 9 mmHg	0.0 %
Pulmonic							
McElhinney et al. [45]	2010	124	n/a	Medtronic Melody	99.2 %	Median peak 12 mmHg	0.8 %

valve procedures in the low pressure system were excellent with no observed 30-day mortality in tricuspid and 0.8 % in pulmonic valve-in-valve patients. The presented results by the "Global Valve-in-Valve Registry" correspond with the before mentioned data. The impediment of the expansion of the catheter valve by the sewing ring might have protective effects with regards to reduced risk for heart block, annular rupture and coronary obstruction [3]. Most experience in valve-in-valve therapies exists with degenerated stented bioprostheses. Of all reported valve-in-valve TAVI 19 % are performed due to deteriorated stentless bioprostheses [44•]. An interesting observation was made by the "Global Valve-in-Valve Registry", which reported a high incidence of left-main stem obstruction in patients receiving valve-in-valve TAVI with the Medtronic CoreValve® for a deteriorated Sorin Freedom® stentless valve [44•]. Anyhow, the total number was low and further data needs to be collected.

Future Directions

Further data concerning valve-in-valve TAVI will be collected and long-term results will become available. With an increase of reported cases, the present experiences will be improved and indications will be pushed further. With upcoming new devices and more available valve sizes, TAVI will be feasible for treating different types and sizes of degenerated bioprostheses. New implantation techniques like echocardiography-guided positioning will reduce the amount of contrast agent and exposure to radiation. Alongside fabricated valves may continuously improve hemodynamic. If valve-in-valve TAVI meets the challenge to be comparable to conventional redo-surgery and possibly can provide better results, it may advance to the treatment of choice for high-risk patients. If sufficient data is available, the implementation of specific indications should be gathered in the present guidelines for treatment valvular heart disease.

Conclusion

Since the first description of TAVI in 2002 by Cribier and colleagues, transcatheter procedures have become an inherent part in every day life in most cardiosurgical centers. The development of the valve-in-valve concept for treatment of degenerated bioprosthesis was the consequential next step and opened numerous possibilities for treatment of valvular heart disease in high risk patients requiring redo-surgery. Experience with this young technique is continuously growing and several studies were published, describing valve-in-valve therapies in aortic, mitral, tricuspid and pulmonic position. The use of the Edwards SAPIEN® valve in aortic and mitral position presents the greatest experience worldwide. For tricuspid and pulmonic valve-in-valve therapies the Medtronic Melody® valve is most commonly used. The present studies report high procedural success with a significant

decrease of transvalvular pressure gradients. Likewise, the clinical results are promising. The reported 30-day mortality-rates range between 0 % and 33.3 %. Limitations of this young technique are small sized bioprostheses. Equal or smaller than a 21 mm Carpentier-Edwards Perimount valve results in incomplete expansion and consecutively may remain with unacceptable high transvalvular gradients. The treatment of destructed valves, after endocarditis, and treatment of paravalvular leakages are not possible with valve-in-valve TAVI. Challenging is the valve-in-valve procedure in the presence of stentless valves or stented valves with external mounted leaflets. In those cases, the missing frame between leaflets and aortic root may increase the risk for coronary obstruction. Nonetheless, with regard to the present reported procedures, valve-in-valve TAVI is feasible and seems to be safe and effective in treatment of patients presenting with deteriorated bioprosthetic valves. Before TAVI can ever be recommended for treatment of choice in redo-valve surgery in high-risk patients, this young technique needs to be compared to conventional redo-surgery and its present superiority. Until then, valve-in-valve TAVI should only be considered in highest-risk patients or patients at prohibitive risk for conventional redo-surgery. Nonetheless, valve-in-valve TAVI is a further step in direction to a tailor-made treatment strategy for high-risk patients.

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References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1.• Wilbring M, Alexiou K, Tugtekin SM, et al. Transapical transcatheter valve-in-valve implantation for deteriorated mitral valve bioprostheses. Ann Thorac Surg. 2012. doi:10.1016/j.athoracsur.2012.08.004. *This article gives detailed information about technical aspects of transapical mitral valve-in-valve TAVI.*
2. Cribier A, Eltchaninoff H, Bash A, et al. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. Circulation. 2002;106:3006–8.
3. Gurvitch R, Cheung A, Ye J, et al. Transcatheter valve-in-valve implantation for failed surgical bioprosthetic valves. J Am Coll Cardiol. 2011;58:2196–209.
4. Seiffert M, Conradi L, Baldus S, et al. Transcatheter mitral valve-in-valve implantation in patients with degenerated bioprostheses. JACC Cardiovasc Interv. 2012;5:341–9.
5.• Piazza N, Bleiziffer S, Brockmann G, et al. Transcatheter aortic valve implantation for failing surgical aortic bioprosthetic valve: from concept to clinical application and evaluation (part 1). JACC Cardiovasc Interv. 2011;4:721–32. *This article provides detailed information about failing mechanisms of prosthetic valves and gives detailed report of several cases.*
6. Jones JM, O'kane H, Gladstone DJ, et al. Repeat heart valve surgery: risk factors for operative mortality. J Thorac Cardiovasc Surg. 2001;122:913–8.
7. Maganti M, Rao V, Armstrong S, et al. Redo valvular surgery in elderly patients. Ann Thorac Surg. 2009;87:521–5.
8. Walther T, Falk V, Dewey T, et al. Valve-in-a-valve concept for transcatheter minimally invasive repeat xenograft implantation. J Am Coll Cardiol. 2007;50:56–60.
9. Kempfert J, Van Linden A, Linke A, et al. Transapical off-pump valve-in-valve implantation in patients with degenerated aortic xenografts. Ann Thorac Surg. 2010;89:1934–41.
10. •• Eggebrecht H, Schäfer U, Treede H, et al. Valve-in-valve transcatheter aortic valve implantation for degenerated bioprosthetic heart valves. JACC Cardiovasc Interv. 2011;4:1218–27. *This well-designed study provides essential information and technical insights about valve-in-valve TAVI.*
11. Wilbring M, Sill B, Tugtekin SM, et al. Transcatheter valve-in-valve implantation for deteriorated aortic bioprosthesis: initial clinical results and follow-up in a series of high-risk patients. Ann ThoracSurg. 2012;93:734–41.
12. Kempfert J, Blumenstein JM, Borger MA, et al. Minimally invasive off-pump valve-in-a-valve implantation: the atrial transcatheter approach for re-operative mitral valve replacement. Eur Heart J. 2008;29:2382–7.
13. Cheung A, Webb JG, Wong DR, et al. Transapical transcatheter mitral valve-in-valve implantation in a human. Ann Thorac Surg. 2009;87:e18–20.
14. Seiffert M, Franzen O, Conradi L, et al. Series of transcatheter valve-in-valve implantations in high-risk patients with degenerated bioprostheses in aortic and mitral position. Catheter Cardiovasc Interv. 2010;76:608–15.
15. Cheung AW, Gurvitch R, Ye J, et al. Transcatheter transapical mitral valve-in-valve implantations for a failed bioprosthesis: a case series. J Thorac Cardiovasc Surg. 2011;141:711–5.
16. Kempfert J, Blumenstein J, Chu MW, et al. Minimally invasive off-pump valve-in-a-ring implantation: the atrial transcatheter approach for re-operative mitral valve replacement after failed repair. Eur J Cardiothorac Surg. 2009;35:965–9.
17. Ghazy T, Kappert U, Ouda A, et al. A question of clinical reliability: observed versus EuroSCORE-predicted mortalityafter aortic valve replacement. J Heart Valve Dis. 2010;19:16–20.
18. • Walther T, Schuler G, Borger MA, et al. Transapical aortic valve implantation in 100 consecutive patients: comparison to propensity-matched conventional aortic valve replacement. Eur Heart J. 2010;31:1398–403. *Well-designed study providing baseline clinical results of the TAVI-procedure in comparison with conventional aortic valve replacement*.
19. Conradi L, Seiffert M, Treede H, et al. Transcatheter aortic valve implantation versus surgical aortic valve replacement: a propensity score analysis in patients at high surgical risk. J Thorac Cardiovasc Surg. 2012;143:64–71.
20. Webb JG, Lichtenstein S. Transcatheter percutaneous and transapical aortic valve replacement. Semin Thorac Cardiovasc Surg. 2007;19:304–10.
21. Kempfert J, Van Linden A, Linke A, et al. Transapical aortic valve implantation: therapy of choice for patients with aortic stenosis and porcelain aorta? Ann Thorac Surg. Nov. 2010;90:1457–61.
22. Christakis GT, Buth KJ, Goldman BS, et al. Inaccurate and misleading valve sizing: a proposed standard for valve size nomenclature. Ann Thorac Surg. 1998;66:1198–203.
23. Shibata T, Inoue K, Ikuta T, et al. Which valve and which size should we use in the valve-on-valve technique for re-do mitral valve surgery? Interact Cardiovasc Thorac Surg. 2009;8:206–10.
24. Nietlispach F, Wijesinghe N, Wood D, et al. Current balloon-expandable transcatheter heart valve and delivery systems. Catheter Cardiovasc Interv. 2010;75:295–300.

25. Azadani AN, Jaussaud N, Matthews PB, et al. Aortic valve-in-valve implantation: impact of transcatheter- bioprosthesis size mismatch. J Heart Valve Dis. 2009;18:367–73.
26. Khawaja MZ, Haworth P, Ghuran A, et al. Transcatheter aortic valve implantation for stenosed and regurgitant aortic valve bioprostheses CoreValve for failed bioprosthetic aortic valve replacements. J Am Coll Cardiol. 2010;55:97–101.
27. Hasan BS, McElhinney DB, Brown DW, et al. Short-term performance of the transcatheter Melody valve in high-pressure hemodynamic environments in the pulmonary and systemic circulations. Circ Cardiovasc Interv. 2011;4:615–20.
28. Kempfert J, Blumenstein J, Chu MW, et al. Minimally invasive off-pump valve-in-a-ring implantation: the atrial transcatheter approach for re-operative mitral valve replacement after failed repair. Eur J Cardiothorac Surg. 2009;35:965–9. discussion 969.
29. • Kondo N, Shuto T, McGarvey JR, et al. Melody valve-in-ring procedure for mitral valve replacement: feasibility in four annuloplasty types. Ann Thorac Surg. 2012;93:783–8. *This article gives an idea of developing fields in valve-in-valve TAVI.*
30. Cerillo AG, Chiaramonti F, Murzi M, et al. Transcatheter valve in valve implantation for failed mitral and tricuspid bioprosthesis. Catheter Cardiovasc Interv. 2011;78:987–95.
31. Jux C, Akintuerk H, Schranz D. Two melodies in concert: Transcatheter double-valve replacement. Catheter Cardiovasc Interv. 2011 Nov 22.
32. Riede FT, Dähnert I. Implantation of a Melody® valve in triscuspid position. Catheter Cardiovasc Interv. 2012;80:474–6.
33. Faza N, Kenny D, Kavinsky C, et al. Single center comparative outcomes of the edwardssapien and medtronic melody transcatheter heart valves in the pulmonary position. Catheter Cardiovasc Interv. 2012 Sep 25.
34. Kapetanakis EI, MacCarthy P, Monaghan M, Wendler O. Trans-apical aortic valve implantation in a patient with stentless valve degeneration. Eur J Cardiothorac Surg. 2011;39 (6):1051–3.
35. Bagur R, Rodés-Cabau J, De Larochellière R, et al. Transfemoral aortic valve-in-valve implantation with a balloon-expandable valve for the treatment of stentless xenograft severe aortic regurgitation. JACC Cardiovasc Interv. 2011;4:1248–9.
36. Finch J, Roussin I, Pepper J. Failing stentless aortic valves: redo aortic root replacement or valve in a valve? Eur J Cardiothorac Surg. 2012 Aug 29.
37. Seiffert M, Baldus S, Conradi L, et al. Simultaneous transcatheter aortic and mitral valve-in-valve implantation in a patient with degenerated bioprostheses and high surgical risk. Thorac Cardiovasc Surg. 2011;59:490–2.
38. Pasic M, Unbehaun A, Dreysse S, et al. Transapical aortic valve implantation after previous aortic valve replacement: clinical proof of the "valve-in-valve" concept. J Thorac Cardiovasc Surg. 2011;142:270–7.
39. Webb JG, Wood DA, Ye J, et al. Transcatheter valve-in-valve implantation for failed bioprosthetic heart valves. Circulation. 2010;121:1848–57.
40. Gotzmann M, Mügge A, Bojara W. Transcatheter aortic valve implantation for treatment of patients with degenerated aortic bioprostheses–valve-in-valve technique. Catheter Cardiovasc Interv. 2010;76:1000–6.
41. Wenaweser P, Pilgrim T, Windecker S, et al. Transapical valve-in-valve implantation for regurgitant stented aortic bioprostheses. J Heart Valve Dis. 2012;21:344–9.
42. Piazza N, Bleiziffer S, Brockmann G, et al. Transcatheter aortic valve implantation for failing surgical aortic bioprosthetic valve: from concept to clinical application and evaluation (part 2). JACC Cardiovasc Interv. 2011;4:733–42.
43. Roberts PA, Boudjemline Y, Cheatham JP, et al. Percutaneous tricuspid valve replacement in congenital and acquired heart disease. J Am Coll Cardiol. 2011;58:117–22.
44. • Danny Dvir, MD, on behalf of the Global Valve-in-Valve Registry investigators. Transcatheter Aortic-Valve Implantation for the Treatment of Degenerative Bioprosthetic Surgical Valves: Results from the Global Valve-in-Valve Registry. Presented at EuroPCR 2012; www.valveinvalve.com. *This is the largest collection of valve-in-valve TAVI up to now*
45. McElhinney DB, Hellenbrand WE, Zahn EM, et al. Short- and medium-term outcomes after transcatheter pulmonary valve placement in the expanded multicenter US melody valve trial. Circulation. 2010;122:507–16.
46. Michelena HI, Alli O, Cabalka AK, Rihal CS. Successful percutaneous transvenous antegrade mitral valve-in-valve implantation. Catheter Cardiovasc Interv. 2012. doi:10.1002/ccd.24423.