

Artículo Original

Valve Thrombosis Following Transcatheter Aortic Valve Implantation: A Systematic Review



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ABSTRACT

Introduction and objectives: Despite the rapid global uptake of transcatheter aortic valve implantation, valve thrombosis has yet to be systematically evaluated in this field. The aim of this study was to determine the clinical characteristics, diagnostic criteria, and treatment outcomes of patients diagnosed with valve thrombosis following transcatheter aortic valve implantation through a systematic review of published data.

Methods: Literature published between 2002 and 2012 on valve thrombosis as a complication of transcatheter aortic valve implantation was identified through a systematic electronic search.

Results: A total of 11 publications were identified, describing 16 patients (mean age, 80 [5] years, 65% men). All but 1 patient (94%) received a balloon-expandable valve. All patients received dual antiplatelet therapy immediately following the procedure and continued to take either mono- or dual antiplatelet therapy at the time of valve thrombosis diagnosis. Valve thrombosis was diagnosed at a median of 6 months post-procedure, with progressive dyspnea being the most common symptom. A significant increase in transvalvular gradient (from 10 [4] to 40 [12] mmHg) was the most common echocardiographic feature, in addition to leaflet thickening. Thrombus was not directly visualized with echocardiography. Three patients underwent valve explantation, and the remaining received warfarin, which effectively restored the mean transvalvular gradient to baseline within 2 months. Systemic embolism was not a feature of valve thrombosis post-transcatheter aortic valve implantation.

Conclusions: Although a rare, yet likely under-reported complication of post-transcatheter aortic valve implantation, progressive dyspnea coupled with an increasing transvalvular gradient on echocardiography within the months following the intervention likely signifies valve thrombosis. While direct thrombus visualization appears difficult, prompt initiation of oral anticoagulation therapy effectively restores baseline valve function.

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Revisión sistemática de la trombosis protésica tras implante percutáneo de válvula aórtica

RESUMEN

Introducción y objetivos: A pesar de la rápida extensión del implante transcáteter de válvulas aórticas, la trombosis protésica tras la intervención es una complicación grave que no se ha evaluado sistemáticamente. El objetivo de este estudio es determinar las características clínicas, los criterios diagnósticos y el manejo de la trombosis protésica tras implante percutáneo de válvula aórtica mediante revisión sistemática de los datos publicados hasta la fecha.

Métodos: Se identificaron, mediante búsqueda electrónica sistemática, todos los artículos publicados en 2002-2012 relacionados con trombosis protésica como complicación tras implante percutáneo de válvula aórtica.

Resultados: Se identificaron 11 publicaciones que describían a un total de 16 pacientes (media de edad, 80 ± 5 años; el 65% varones) con trombosis protésica subaguda. En todos los casos excepto 1 (94%), se utilizaron prótesis de tipo balón expandible. Todos los pacientes recibieron doble antiagregación inmediatamente después del procedimiento y continuaban recibiendo al menos un antiagregante en el momento del diagnóstico, que se realizó una mediana de 6 meses tras el implante. La disnea progresiva fue el síntoma más común de presentación. El principal hallazgo ecocardiográfico fue un incremento en los gradientes transvalvulares (media de 10 ± 4 mmHg tras el implante a 40 ± 12 mmHg al diagnóstico), junto con el engrosamiento en las valvas. No se visualizaron directamente trombos mediante la ecocardiografía. En 3 casos la prótesis se substituyó quirúrgicamente, mientras que el resto recibió warfarina, que consiguió un

Palabras clave:

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descenso efectivo de los gradientes en una mediana de 2 meses. No se produjeron embolias como consecuencia de la trombosis valvular tras implantación percutánea de la válvula.

Conclusiones: Aunque infrecuente y probablemente infracomunicada, ante la aparición de disnea progresiva junto con aumento de gradientes en los meses siguientes al implante transcáteter de válvula aórtica, se debe pensar en trombosis protésica. Aunque la visualización directa del trombo resulta difícil, la instauración precoz de anticoagulación oral puede restaurar de manera efectiva la función protésica. © 2014 Sociedad Española de Cardiología. Publicado por Elsevier España, S.L.U. Todos los derechos reservados.

Abbreviations

ASA: acetylsalicylic acid
OAC: oral anti-coagulation
SAVR: surgical aortic valve replacement
TAVI: transcatheter aortic valve implantation
VT: valve thrombosis

INTRODUCTION

Valve thrombosis (VT) following surgical valve replacement is a life-threatening complication largely involving mechanical prostheses and is commonly associated with subtherapeutic oral anticoagulation (OAC) therapy.¹ Bioprosthetic surgical aortic valves rarely thrombose, with an estimated incidence of 0.01% to 1.26%.^{2–5} Transcatheter aortic valve implantation (TAVI) is an established treatment for severe symptomatic aortic stenosis among patients whose surgical complication risk is deemed prohibitive or high.⁶ While thromboembolic complications of TAVI, particularly periprocedural cerebrovascular events, are well described,^{7–9} little is known of the occurrence of VT following TAVI. To date, an estimated 150 000 TAVI procedures or more have been performed worldwide. However, data on this critical complication is currently limited to isolated case reports or small case series, precluding a more formal evaluation of its chief clinical characteristics, management strategies, and outcomes.^{10–22} The objective of this systematic review is to provide further insight into the baseline characteristics, clinical presentation, management, and outcomes of patients diagnosed with VT following TAVI.

METHODS

A comprehensive and systematic search of all English-language articles in PubMed, Google Scholar, Cochrane Library, and BioMedCentral addressing thrombosis as a complication of TAVI was performed using the following keywords: “transcatheter aortic valve”, “transcatheter prostheses”, “TAVI”, “transcatheter aortic valve replacement”, “thrombosis”, “thrombus”, “dysfunction”, “obstruction”, “degeneration”, “stenosis”. A manual search was also performed of the major TAVI-related trials and registries. All publications were retrieved and evaluated independently by 2 investigators (J.G. Córdoba-Soriano and I. Amat-Santos). Articles reporting thrombosis of transcatheter valves in nonaortic positions were excluded. The data gathered included baseline demographics and clinical characteristics, diagnostic imaging, antithrombotic therapies post-TAVI, treatment of VT *per se*, and clinical outcomes. Echocardiographic data included left ventricular ejection fraction, valve area and gradients, and the presence of paravalvular leaks.

Statistical Analysis

Categorical variables are reported as No. (%) and continuous variables as mean (standard deviation) or median according to

variable distribution. All analyses were performed with SAS version 9.2 (SAS Institute Inc.; Cary, North Carolina, United States).

RESULTS

Thirteen reports describing 18 cases of thrombosis as a complication of TAVI were identified,^{10–22} including 2 individuals with periprocedural VT who are listed and described separately as “acute” VT.^{12,20}

Table 1 describes the baseline and procedural characteristics of patients with VT post-TAVI. The mean age was 80 (5) years, with a male preponderance. Atrial fibrillation was not reported in any of the patients, and left ventricular ejection fraction was described in only 5 patients. Coagulopathy was tested in 10 patients (63%), one of whom had a 50% reduction in protein S activity and tested positive for cold agglutinins. Two patients had a prior history of stroke and 1 patient was receiving chronic OAC for prior pulmonary embolism. The absence of systemic inflammatory disease was highlighted in most patients and allergy to the prosthetic components was ruled out in 2 of them.

In all but 1 patient, TAVI was performed to treat severe native aortic valve stenosis; this patient underwent a valve-in-valve procedure for failure of a prior surgically-implanted prosthetic aortic valve. All but 1 patient underwent TAVI using a balloon-expandable Edwards SAPIEN valve (25% Edwards SAPIEN, 69% SAPIEN XT) (Edwards Lifesciences Inc.; Irvine, California, United States). One patient (6%) received a self-expandable CoreValve® (Medtronic; Minneapolis, Minnesota, United States). The implanted valve sizes ranged from 26 mm in 47% of the patients to 23 mm and 29 mm in 20% and 27% of the patients, respectively. Post-TAVI echocardiography demonstrated a mean transvalvular gradient of 10 (4) mmHg and the presence of residual aortic regurgitation was reported in 4 patients (29%). All patients received antiplatelet therapy post-TAVI, with dual antiplatelet therapy (acetylsalicylic acid [ASA] + clopidogrel for 1–6 months) being the most frequent (86%) regimen. No patient received OAC post-TAVI. Valve thrombosis was eventually diagnosed at a median time of 6 (0.5–24) months post-TAVI.

Table 2 describes the clinical presentation, diagnostic tests, and results of echocardiography at the time of presentation. Most patients experienced progressive dyspnea, and 2 patients presented with refractory heart failure. Infectious endocarditis was excluded in all patients. Upon presentation with VT, most (63%) patients were actively receiving antiplatelet therapy: ASA monotherapy, 6 patients (38%); ASA + clopidogrel, 3 patients (19%); clopidogrel monotherapy, 1 patient (6%). Two patients (13%) were not receiving antithrombotic treatment at the time of VT, and no data on antithrombotic treatment were available in a further 3 patients (19%). No patient was receiving OAC at the time of VT diagnosis.

Echocardiography revealed VT in most patients, characterized by an increase from baseline in transvalvular gradient (94% of patients), with a mean gradient at the time of VT diagnosis being 43 (12) mmHg. Additionally, increased valve thickness or restricted leaflet mobility was described in a number of patients, whereas direct echocardiographic visualization of thrombus in all

Table 1
Baseline Demographic, Clinical and Procedural Characteristics

Patient	Age	Gender	STS/EuroSCORE	Risk factors	Valvulopathy	Type of valve, size (mm)	Approach	Antithrombotic treatment		Time from implantation
								Postintervention	At the time of thrombosis	
1 ¹⁰	84	Female	—/22%	Yes ^a	Severe AS	SAPIEN, 23	TA	ASA indefinitely, clopidogrel 6 months	No ^b	6 months
2 ¹¹	78	Male	—/44%	—	Severe AS	SAPIEN, 26	TA	ASA indefinitely, clopidogrel 1 month	ASA	4 months
3 ¹³	83	Male	5%/30%	History of stroke	Severe AS	SAPIEN XT, 26	TF	ASA indefinitely, clopidogrel 6 months	ASA, clopidogrel	6 months
4 ¹³	81	Male	3.9%/11%	—	Severe AS	SAPIEN XT, —	TF	ASA, clopidogrel 3 months	ASA	15 months
5 ¹³	83	Male	17%/20%	History of stroke	Severe AS	SAPIEN XT, 26	TF	—	—	24 months
6 ¹⁴	80	Female	—/—	No	Severe AS	SAPIEN XT, 23	—	ASA, clopidogrel	ASA, clopidogrel	10 months
7 ¹⁴	81	Male	—/—	—	Bioprosthetic dysfunction	SAPIEN XT, 23	—	—	—	4 months
8 ¹⁴	74	Female	—/—	—	Severe AS	SAPIEN XT, 26	—	ASA, clopidogrel	—	2 months
9 ¹⁵	74	Female	18.7%/—	No	Severe AS	SAPIEN, 23	TF ^c	ASA < 2 week	No	2 weeks
10 ¹⁶	86	Male	—/7%	No	Severe AS	CoreValve®, 26	—	ASA indefinitely, clopidogrel 3 months	ASA	6 months
11 ¹⁷	86	Male	—	History of PE	Severe AS	SAPIEN XT, 29	—	ASA, clopidogrel	ASA, clopidogrel	1 week
12 ¹⁸	81	Female	—/—	—	Severe AS	SAPIEN, 26	—	ASA	ASA	20 months
13 ¹⁹	87	Male	15.6%/29%	No	Severe AS	SAPIEN XT, 29	TA	ASA indefinitely, clopidogrel 3 months	Clopidogrel ^d	8 months
14 ²¹	70	Male	—/—	—	Severe AS	SAPIEN XT, 26	TF	ASA indefinitely, clopidogrel 1 months	ASA	6 months
15 ²²	—	—	—/—	—	Severe AS	SAPIEN XT, 29	TA	UFH 5 days, ASA indefinitely, clopidogrel 12 months	ASA	3 months
16 ²²	—	—	—/—	—	Severe AS	SAPIEN XT, 29	TA	UFH 5 days, ASA indefinitely, clopidogrel 12 months	ASA	4 months
Acute thrombosis cases										
17 ¹²	66	Male	—/—	—	Severe AS	SAPIEN, 23	TF		UFH, ASA, clopidogrel	Acute
18 ²⁰	90	Male	17%/—	PAF	Severe AS	SAPIEN, 26	TF		UFH, ASA, clopidogrel	Acute ^e

AS, aortic stenosis; ASA, acetylsalicylic acid; PAF, paroxysmal atrial fibrillation; PE, pulmonary embolism; STS, Society of Thoracic Surgeons; TA, transapical; TF, transfemoral; UFH, unfractionated heparin.

^a Mild reduction of protein S activity (50%) and positive cold agglutinins were detected.

^b The patient discontinued the treatment.

^c Performed across an iliac conduit.

^d Patient discontinued acetylsalicylic acid due to recurrent epistaxis.

^e Hydrophilic polymer embolism-induced acute thrombosis. Cardiac arrest 18 h following the procedure.

Table 2
Clinical Manifestations, Diagnostic Techniques and Echocardiographic Data

Patient	Clinical presentation			Diagnostics techniques						Echocardiographic data				
	Progressive dyspnea	NYHA class	Other	TTE	TEE	CT	Angio	ICE	LVEF	AR post-TAVI	Valve thickness	MG post-TAVI	MG at diagnosis	MG post-treatment
1 ¹⁰	Yes	—		Yes	Yes		Yes		—	No	Yes	17	40	—
2 ¹¹	Yes	—	NSTEMI		Yes		Yes	Yes	30%	Trivial	Yes	—	—	—
3 ¹³	Yes	II		Yes	Yes				Normal	No	Yes	11	47	11
4 ¹³	Yes	II		Yes	Yes				Normal	Trivial	—	8	45	19
5 ¹³	Yes	III		Yes	Yes				Normal	Mild	—	9	37	13
6 ¹⁴	Yes	III		Yes	Yes				—	—	Yes	10	54	13
7 ¹⁴	Yes	III		Yes	Yes				—	—	Yes	15	51	9
8 ¹⁴	Yes	II		Yes	Yes				—	—	—	7	34	9
9 ¹⁵	Yes	III		Yes					59%	No	Yes	5	43	28
10 ¹⁶	Yes	III		Yes	Yes	Yes			—	—	Yes	—	41	—
11 ¹⁷	No	I	Asymptomatic		Yes	Yes			—	Trivial	Yes	—	9	—
12 ¹⁸	Yes	—		Yes	Yes				—	—	Yes	—	53	10
13 ¹⁹	Yes	III		Yes	Yes				60%	—	Yes	8	50	9
14 ²¹	Yes	—	Angina		Yes	Yes			—	—	Yes	—	48	6
15 ²²	Yes	IV	Death			Yes			—	—	Yes	—	—	—
16 ²²	Yes	IV	Death			Yes			—	—	Yes	—	—	—
Acute thrombosis cases														
17 ¹²	No	—	Cardiac arrest		Yes					No	Yes	—	—	—
18 ²⁰	No	—	Cardiac arrest		Yes		Yes			—	—	—	—	—

AR, aortic regurgitation; CT, computed tomography; ICE, intracardiac echo; LVEF, left ventricular ejection fraction; MG, mean gradient; NSTEMI, non—ST-segment elevation myocardial infarction; NYHA, New York Heart Association; TAVI, transcatheter aortic valve implantation; TTE, transthoracic echocardiography; TEE, transesophageal echocardiography.

patients appeared elusive. Computed tomography was performed in 5 patients, however, and revealed hypodense structures compatible with thrombus.

Table 3 describes the clinical management of VT. No patient underwent thrombolysis, and most patients (78%) received OAC

therapy, with 3 patients undergoing surgical replacement. Concomitant antiplatelet therapy was reported in 4 patient. Mean transvalvular gradients were successfully reduced by OAC at a median time of 2 (1-10) months. A definitive diagnosis of VT was made in 5 patients following direct visualization at surgery or

Table 3
Thrombosis Management and Clinical Outcomes

Patient	Management of thrombosis						Treatment at discharge			Time to success, months	Histopathologic confirmation
	ASA	Clopidogrel	VKA	UFH	LMWH	Surgery	ASA	Clopidogrel	VKA		
1 ¹⁰	—	—	—	—	—	Yes	—	—	—	—	Yes
2 ¹¹	—	—	Yes	Yes	—	No	—	—	Yes	1	No
3 ¹³	Yes	Yes	Yes	—	—	No	Yes	Yes	Yes	2	No
4 ¹³	Yes	No	Yes	—	—	No	Yes	No	Yes	2	No
5 ¹³	—	—	Yes	—	—	No	—	—	—	2	No
6 ¹⁴	—	—	Yes	—	—	No	—	—	Yes	3	No
7 ¹⁴	—	—	Yes	—	—	No	—	—	Yes	2	No
8 ¹⁴	—	—	Yes	—	—	No	—	—	—	2	No
9 ¹⁵	—	—	—	—	—	Sí	Yes	No	Yes	—	Yes
10 ¹⁶	—	—	—	—	—	Sí	—	—	—	—	Yes
11 ¹⁷	—	—	Yes	—	—	No	—	—	Yes	2.5	No
12 ¹⁸	—	—	Yes	—	Yes	No	—	—	Yes	10	No
13 ¹⁹	Yes	No	Yes	Yes	No	No	Yes	No	Yes	1	No
14 ²¹	Yes	Yes	Yes	—	—	No	Yes	Yes	Yes	3	No
15 ²²	—	—	—	—	—	No					Yes
16 ²²	—	—	—	—	—	No					Yes
Acute thrombosis cases											
17 ¹²	—	—	—	Yes	—	No					Yes
18 ²⁰	Yes	Yes	No	Yes	No	No					Yes

ASA, acetylsalicylic acid; LMWH, low molecular weight heparin; UFH, unfractionated heparin; VKA, vitamin K antagonist.

during post-mortem examination, whereas the remaining cases were considered VT following significant reductions in transvalvular gradients during OAC therapy.

Acute Valve Thrombosis Post-transcatheter Aortic Valve Implantation

Two cases of VT occurred acutely following transfemoral TAVI with a first-generation Edwards SAPIEN valve. Both patients had received preprocedural dual antiplatelet therapy in addition to periprocedural unfractionated heparin. One case involved preprocedural discontinuation of OAC, initially prescribed for low left ventricular ejection fraction pre-TAVI. Following valve implantation, echocardiography revealed thrombus adhering to the stent frame in each patient. In both patients, unfractionated heparin was continued and in 1 particular patient, attempts at manual thrombus aspiration proved unsuccessful.

DISCUSSION

Bioprosthetic valves are generally considered less thrombo-genic than their mechanical counterparts, in many instances obviating the need for long-term OAC. Nevertheless, the risk of thromboembolic events is not insignificant, particularly within the first 3 months following surgical aortic valve replacement (SAVR).^{23,24} The incidence of VT following SAVR is estimated to range from 0.03 events per 100 patient years,²⁵ with reports of a 15-year incidence of 0.37% to 26%.^{3,26} Since the inception of TAVI in 2002,²⁷ and despite an estimated 150 000 procedures or more having now been performed worldwide, large-scale clinical trials and registries have formally reported a single VT case.^{28–38} Moreover, a number of isolated clinical descriptions of VT post-TAVI coupled with largely empiric peri- and post-procedural antithrombotic regimens following TAVI underscores the importance of a timely systematic review of this poorly described phenomenon.

Several pertinent findings have emerged from this systematic review:

- Most VT cases occurred within 1 year after TAVI, with a median time of onset of 6 months.
- Almost all patients described gradual onset of increasing dyspnea, with the absence of clinical embolism. Although direct thrombus visualization was not described with echocardiography, suggestive echocardiographic morphological features included reduced leaflet mobility, increased leaflet thickening, and progressively increasing transvalvular gradients.
- A preponderance of VT cases post-TAVI occurred following balloon-expandable valve implantation.
- Valve thrombus post-TAVI was successfully treated following prompt OAC therapy, effectively restoring transcatheter valve function and hemodynamic performance.

Clinical Presentation and Diagnostic Tools

Following the initial symptom relief after TAVI for severe aortic stenosis, increasing dyspnea coupled with a progressively rising transvalvular gradient was a near universal finding among patients with VT post-TAVI. These findings appear analogous to the nature and timing of VT post-SAVR utilizing bioprostheses.^{3–5} The median time following TAVI for the diagnosis of VT was 6 months, with most cases being diagnosed within 1-year post-TAVI. This compares with a peak incidence for surgically-implanted aortic

bioprostheses occurring at 13 months to 24 months reported by Pislaru et al.⁴ and a median time of 12 months post-SAVR reported by both Brown et al.³ and Jander et al.³⁹ The immediate implications of the present findings relate to promoting a heightened clinical awareness for the possibility of VT post-TAVI, particularly among patients with worsening dyspnea following TAVI. An important observation was that direct visualization of a valve-related thrombus seems not to be a requirement for diagnosis and management. Rather, in patients with an elevated (or rising) echocardiographic transvalvular gradient, the diagnosis of VT should be strongly suspected, rather than simply valve degeneration. Whilst computed tomography imaging may provide supportive visual evidence of thrombus, this should not preclude the initiation of OAC (at the expense of antiplatelet therapy) as an effective means of eradicating TAVI-related VT. Interestingly, transesophageal echocardiography seemed unable to clinch the diagnosis of VT in many of the reported cases.

Currently, no formal clinical criteria exist for diagnosing VT post-TAVI. Pislaru et al.⁴ proposed, from their series of surgically implanted aortic bioprostheses, that an increase in transvalvular gradient of > 50% from baseline within 5 years following SAVR (in the absence of increased flow), coupled with the presence of thickened/immobile cusps (or the presence of an overt mobile mass) should signify the likely presence of VT.⁴ However, direct extrapolation of these criteria to the TAVI population without formal, prospective evaluation may be somewhat premature. Importantly, these criteria should not currently serve as a barrier for implementing OAC therapy in patients strongly suspected of having VT following TAVI.

Prevention and Management of Valve Thrombosis Post-transcatheter Aortic Valve Implantation

Following SAVR with a bioprosthetic valve, various treatment guidelines are concordant in recommending ASA or OAC therapy during the initial 3 months after surgery, followed by long-term ASA monotherapy.^{40,41} However clinical practice remains heterogeneous,^{42–46} probably because such guidelines are essentially based on observational, retrospective data.^{23,24,47,48}

Following TAVI, dual antiplatelet therapy (ASA + clopidogrel) is currently recommended and used in most centers, but the duration of clopidogrel varies widely among studies (ranging from 1 month to 6 months).⁴⁹ This lack of consensus is reflected by the significant heterogeneity of post-TAVI antithrombotic management described among VT cases in the present review, whereby 57% of patients were receiving ASA monotherapy and 21% were receiving dual antiplatelet therapy at the time of VT diagnosis. Merie et al.⁴⁸ noted a reduced risk of thromboembolic events and cardiovascular death with OAC therapy in the immediate 6-month period following SAVR with bioprosthetic valves. Clinical guidelines stipulate that thromboembolic risk factors such as atrial fibrillation, left ventricular systolic dysfunction, prior thromboembolism, and a known hypercoagulable state are important reasons for considering OAC following surgical aortic bioprosthetic valve deployment.^{40,41} Six (38%) patients in the present VT post-TAVI cohort had risk factors for thrombosis. This highlights the importance of an individualized approach for post-TAVI thromboembolic prophylaxis. Future studies, such as the ongoing ARTE (Aspirin versus Aspirin Clopidogrel Following Transcatheter Aortic Valve Implantation) pilot trial (NCT01559298) should provide key data informing future large-scale, clinical trials.

While traditional definitive management strategies of VT following SAVR encompassed either repeat surgery or thrombolysis, these treatment options involve considerable risk.^{39,50,51} Most patients with TAVI-related VT were successfully managed with

OAC therapy, and these patients experienced significant clinical and hemodynamic improvement, with normalization of transvalvular gradients after 2 months of OAC therapy. These findings appear analogous to the successful use of OAC therapy for treating VT in the bioprosthetic SAVR or mitral valve population.^{4,39,51} Collectively, these findings support the rationale for commencing OAC therapy in post-TAVI patients suspected to harbor VT, including those with progressive dyspnea, valve leaflet thickening, restricted leaflet mobility, and a progressively rising echocardiographic transaortic gradient. The duration of OAC, however, remains unclear and should be determined on an individual basis. In the event of OAC cessation, we recommend institution of dual antiplatelet therapy and frequent echocardiographic surveillance.

Differing Thrombosis Rates Across Balloon vs Self Expanding Transcatheter Aortic Valves

Most VT cases were reported following balloon-expandable valve implantation. Although it is difficult to determine the precise mechanisms underscoring these observations, it is likely that VT post-TAVI relates to the complex interplay of a number of patient-, procedural-, and valve-related phenomena. Both the Edwards SAPIEN and CoreValve[®] are stented pericardial valves incorporating bovine and porcine tissue, respectively.^{6,52} However, the stented-frame design and composition of each valve differs substantially; the CoreValve[®] is longer and nitinol-based compared with the shorter and stainless steel or cobalt-chromium-based Edwards SAPIEN valve. It is plausible that the metallic frame could serve as a nidus for thrombus, particularly until complete endothelialization occurs, which could take up to 12 months or more.^{9,53,54} Additionally, the Edwards SAPIEN valve contains a polyethylene terephthalate skirt, designed to minimize paravalvular regurgitation, not present on the CoreValve[®]. Nevertheless, Ducci et al⁵⁵ observed *in vitro* that both transcatheter aortic valve designs result in reduced sinus of Valsalva flow, contributing to relative blood stasis on the aortic side of the valve. Compounding these valve-related hemodynamic factors is the likely occurrence of native valve leaflet fissuring, perforation, and endothelial denudation following balloon dilatation prior to balloon-expandable TAVI, providing additional stimuli for a localized prothrombotic milieu.

Limitations

Several limitations of the current review warrant consideration. The present analysis is likely to be affected by reporting/publication bias, thus limiting an accurate estimation of the true incidence of VT after TAVI and its clinical characteristics. This furthermore precludes any meaningful conclusions of the differing rates of VT across balloon expandable vs self-expanding valve designs. An added degree of reporting bias is likely to be present in the large number of patients who died at varying time intervals following TAVI and who did not undergo formal diagnostic evaluation or post-mortem examination either prior to or following death. Additionally, other clinical associations (ie, atrial fibrillation, thrombophilias, etc) may not have been systematically reported or assessed. Despite this, the present systematic review serves as an original collective summary of an important, preventable, and treatable complication following TAVI.

CONCLUSIONS

As the global uptake of TAVI for treating severe aortic stenosis remains exponential, rare complications of this evolving treatment

paradigm will continue to be encountered more frequently. Given the present uncertainty of the optimal peri- and post-procedural antithrombotic regimen during TAVI, clinicians should have a heightened awareness of VT following TAVI. The direct visualization of thrombus is not necessary for a diagnosis of VT following TAVI. Rather, in patients with progressive dyspnea and a rising echocardiographic transaortic gradient, OAC therapy may be an effective means of restoring normal valve function.

CONFLICTS OF INTEREST

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