Journal of Cardiology 73 (2019) 126–133

Contents lists available at ScienceDirect

Journal of Cardiology

journal homepage: www.elsevier.com/locate/jjcc

Review

Prosthetic valve endocarditis – A trouble or a challenge?

Branislava Ivanovic (MD, PhD)[a], Danijela Trifunovic (MD, PhD)[a], Snezana Matic (MD)[a], Jelena Petrovic (MD)[a], Dalila Sacic (MD)[a], Marijana Tadic (MD, PhD)[b,*]

[a] Clinical Centre of Serbia, Cardiology Clinic, Belgrade, Serbia
[b] Department of Cardiology, Charité-University-Medicine Berlin, Campus Virchow Klinikum, Berlin, Germany

ARTICLE INFO

Article history:
Received 11 July 2018
Received in revised form 17 August 2018
Accepted 20 August 2018
Available online 30 October 2018

Keywords:
Prosthetic valve
Endocarditis
Diagnosis
Complications

ABSTRACT

Prosthetic valve endocarditis (PVE) represents a rare and serious complication of valve replacement associated with high morbidity and mortality, which significantly differs from native valve endocarditis (NVE). There are two major problems: establishing diagnosis and treatment of PVE. Diagnosis in PVE is challenging and often requires several imaging methods besides standard microbiological analyzes. Transesophageal echocardiographic examination remains the widely used imaging technique in PVE diagnosis, but additional techniques such as computed tomography (CT) and ^{18}F-fluodeoxyglucose positron emission tomography/CT are often necessary. Persistent fever, embolic complications, valve dehiscence, intracardial abscess, heart failure, as well as staphylococcal and fungal PVE require surgical treatment to avoid lethal outcome. The introduction of transcatheter valve implantations and devices significantly complicated the approach – diagnostic and therapeutic to PVE patients. Despite constantly increasing knowledge regarding pathogenesis and treatment of PVE, the optimal therapy remains a matter of debate. Additional studies are necessary to define therapeutic strategies for this potentially fatal complication.

Contents

Introduction

Prosthetic valve endocarditis (PVE) is a serious, life-threatening complication of valve replacement accounting for 10–30% of all cases of infective endocarditis (IE) with an incidence of 0.3–1.2% per patient per year [1]. Patients with prosthetic heart valves are considered at high risk for IE developing [2,3]. There are different findings regarding the incidence and survival rates of PVE on mechanical and biological prosthetic valves [4,5].

Due to diagnostic and treatment advances the mortality rate of PVE has significantly decreased over time – from 56 to 60% in the 1970s to 22.8% at the beginning of this century [3,6]. However, mortality remains high and the reason could lie in the fact that complications are more frequent due to specific pathogenesis, predominantly in early PVE [7]. Even with timely diagnosis, antibiotic treatment and valve replacement, the mortality rate

* Corresponding author at: Department of Cardiology, Charité-University-Medicine Berlin, Campus Virchow Klinikum (CVK), Augustenburger Platz 1, 13353 Berlin, Germany.
E-mail address: marijana_tadic@hotmail.com (M. Tadic).

https://doi.org/10.1016/j.jjcc.2018.08.007
0914-5087/

ranges from 26% to 75% in medically treated patients versus 23–43% in surgically treated patients [2].

Epidemiology

Østergaard et al. in the recently published study that included a large number of patients at high risk for IE showed that the incidence of IE was 16.1/1000 person-years [95% confidence interval (CI) 14.6–17.8/1000 person-years] among patients with prior IE (including patients who had valve surgery during the first IE hospitalization) and 6.0/1000 person-years (95% CI 5.5–6.5/1000 person-years) among patients with a prosthetic heart valve [5]. In the patients with a prosthetic valve the cumulative risk of IE was 2.8% and 4.5% at 5 and 10 years, respectively [5]. In comparison with the matched controls, the patients with a prosthetic valve were associated with a significant increased risk of IE (HR 19.1, 95% CI 15.0–24.4) [5].

An Italian study investigated patients with PVE and revealed that early PVE (in the first 12 months after surgery) was detected in 43% of patients, whereas late PVE (after 12 months since the operation) was diagnosed in 57% of patients [8]. Aortic valve was involved in 66.5%, mitral in 40.7%, tricuspid in 2.9%, and multivalvular in 7.2% of PVE patients [8].

A Danish study reported that patients with a mitral and aortic bioprosthetic valve were related with a higher risk of IE compared with patients with mechanical aortic and mitral valves [4]. A large study in older patients also reported lower 12-year IE incidence in patients with mechanical aortic valve than in subjects with bioprosthetic aortic valve (1.4% vs. 2.2%) [9]. However, these results should be interpreted with caution considering their retrospective nature which does not allow the determination of causal relationship between valve type (mechanical vs. bioprosthetic) and risk of IE. There are also studies that did not find any association between type of prosthetic valve and IE occurrence [10,11]. Nevertheless, these studies did not have IE as a primary endpoint, and therefore their power might be inadequate to detect any differences between valve types. A large meta-analysis showed that the recurrence of endocarditis and the risk of reoperation were higher in the biological valve group [12]. There was no significant difference in survival rates between the biological valve group and the mechanical valve group in patients with PVE.

Pathogenesis

Mechanical and bioprosthetic valves may be affected by the infection, and the prevalence is similar at 5 years (5.7%). It seems that mechanical valves are at higher risk of infection during the first 3 months after operation [4,5]. Considering significant differences in causal microorganisms between PVE which occurs within 1 year of operation and later, it is accepted that the cut-off period for the definition of early and late PVE is 12 months after surgical intervention [1,2,7]. Early PVE (occurring in a period of one year) is most commonly seen in the first two months after the valve replacement and it is caused by microorganisms that invade the prosthesis during valve replacement operation or due to hematogenic dissemination in the first days or months. Interestingly, similar microbiologic profiles were observed between PVE occurring within 2 months of valve replacement and PVE occurring between 2 and 12 months after surgery [9].

By invading the prosthetic ring, microorganisms interfere with perivalvular tissue, which increases the risk of abscess, pseudoaneurysm, or fistula formation and valvular dehiscence. The absence of endothelization of mechanical prosthesis in the early postoperative period contributes to the thrombotic risk.

Given the fact that endothelization of the prosthesis occurs over time, the risk of late PVE development is equivalent to the risk of native valve endocarditis (NVE). Eventually when thrombi consisting of fibrin and thrombocytes are formed, they serve as an appropriate medium for adhesion of microorganisms. The perivalvular tissue is significantly less affected in late PVE, independently of the pathogen virulence. PVE infection is more invasive and more often complicated by perivalvular abscess formation and valve dehiscence. In bioprosthetic valves, infection usually occurs 18 months after valve replacement and affects mainly leaflets, causing appearance of vegetation or even leaflet perforation [13].

In the first year after the valve replacement aortic and mitral valves are equally affected with no difference in the mechanical and biological prosthesis involvement [14]. The time of PVE development is related to the causative agent [7,15,16]. The most common microorganisms causing early PVE (within two months of implantation) are *Staphylococcus aureus* (36%), coagulase negative staphylococci (17%), and fungi. In PVE occurring later, the incidence of *S. aureus* and coagulase negative staphylococci decreases (18–20%) in favor of the enterococci and *Streptococcus viridans* (10–13%). Patients with PVE caused by *S. aureus* represent a unique subgroup characterized by increased risk of complications and higher mortality [17]. Causative agents in late PVE are similar to those in native valve endocarditis.

PVE caused by *Candida* species is a rare but devastating disease with mortality rates reaching 37–62.5% in published case series [18,19]. Nosocomial- or healthcare-associated infections are a dominant cause of this PVE.

Right-sided IE is uncommon, accounting for only 5–10% of cases of IE, with the vast majority (90%) involving the tricuspid valve [20]. Right- and left-sided IE clinically represents two different entities. Studies that included only right-sided IE showed that PVE of tricuspid valve was present in only 11% of all tricuspid valve IE, whereas PVE of pulmonary valve was present in 43% of all pulmonary valve IE [20]. The incidence of right-sided IE significantly increased after the introduction of novel devices for resynchronization therapy and defibrillators. Investigators showed that right-sided IE was more benign than left-sided IE, despite the greater prevalence of *S. aureus* and only 5–16% right-sided IE patients did not respond to medical therapy [21].

A new chapter in PVE represents the IE of the transcatheter-implanted valves and percutaneous edge-to-edge mitral valve repair. The incidence of IE after transcatheter aortic valve implantation (TAVI) is about 1% [22], and it is higher in male patients. The causative agents of TAVI IE are coagulase-negative staphylococci, *S. aureus*, enterococci, and oral streptococci. Less common causal agents include Gram-negative bacteria [23]. The use of transfemoral access in TAVI and the proximity of the groin with the genitourinary/intestinal system increase the risk of enterococci infection (34.4%), whereas staphylococci are dominant (29.4%) with transapical TAVI approach [24]. Amat-Santos et al. reported that enterococci were mostly found after TAVI (34.4%), and *S. aureus* after transcatheter pulmonary valve replacement (29.4%) [22]. The investigators reported that in more than a half of TAVI patients vegetations were localized on the valvular leaflets and less often on the stent or both structures. Surrounding structures are rarely involved [22].

The risk of IE in patients with percutaneous edge-to-edge mitral valve repair (MitraClip, Abbott, Abbott Park, IL, USA) is low [25]. The large registry of MitraClip patients did not report a single case of IE during a 5-year follow-up period [25]. In the incidental cases of MitralClip IE the main cause is *Staphylococcus* and predisposing conditions are the high-risk profile of MitraClip patients and technical issues (reimplantation of malpositioned clips) [25].

Diagnosis

There is no clinical presentation characteristic only for PVE [1]. Patients usually present with fever and loss of appetite. As these

symptoms are commonly seen postoperatively, they often remain neglected. New heart murmur, left bundle brunch block, heart failure, or embolic events are suggestive for PVE. Other signs such as Osler's nodes, Janeway's lesions, and Roth's spots are not common in these patients [26]. Myocardial infarction could be a complication that develops due to coronary artery embolization. The primary cause of a sudden death is usually disruption of the valve.

The diagnosis of PVE is based on positive blood cultures and the echocardiographic findings of vegetation, paravalvular abscess, fistula, or valve dehiscence, as in the case of native valve endocarditis (NVE). However, blood cultures often remain sterile, especially in early PVE, due to previous use of antibiotics. In the absence of prior administration of antibiotics, blood cultures are positive in 90% of patients with PVE. Besides sterile samples, a single blood culture with isolated coagulase-negative *Staphylococcus* might be a diagnostic challenge, which requires a DNA test with pulsed-field gel electrophoresis in order to exclude PVE [26]. The presence of a polyclonal infection in PVE may be the result of direct contamination of the operation room.

Imaging in PVE is challenging [27]. Table 1 summarizes the available data regarding different imaging techniques commonly used in clinical practice. Transesophageal echocardiography (TEE) is necessary in all cases of suspected PVE for valvular hemodynamics assessment and eventual detection of vegetation, abscess, or fistula. It is useful in estimating the mobility of the leaflets and the stability of the ring. Detection of vegetation may be difficult due to artifacts from the valves and therefore transthoracic echocardiography (TTE) could not be considered as a gold standard. The sensitivity of TEE in detection of PVE, i.e. vegetation, abscess, and perivalvular lesions ranges from 82% to 96% in contrast to TTE with the sensitivity of 17% to 36% [28,29]. The negative predictive value of both TTE and TEE in patients with suspected PVE ranges from 86% to 94% [30,31]. In case of unconfirmed, but highly suggestive PVE, it is necessary to repeat the echocardiographic examination after seven days.

The benefit of both TTE and TEE in detection of PVE is lower than in case of NVE. The absence of large comparative studies of multislice computed tomography (MSCT) and echocardiography efficacy in the diagnosis of paravalvular abscesses, vegetations, pseudoaneurysms, and valve dehiscence excludes the possibility of claiming the equivalent or superior efficacy of MSCT [32]. Additionally, it provides an anatomical assessment of the coronary arteries, which is significant in the preoperative evaluation of PVE patients.

In recent years, ^{18}F-fluodeoxyglucose positron emission tomography/computed tomography (^{18}F-FDG PET/CT) scan [33] has been used as the supplementary diagnostic method in the cases of suggestive PVE. It is based on the high sensitivity of ^{18}F-FDG PET/CT in detection of inflammatory activity within the focus of infection. The benefit of this method in diagnosing PVE and infectious endocarditis on intracardial devices has been unequivocally proven [32]. The finding of abnormal ^{18}F-FDG accumulation at the site of an artificial valve has become a new major criterion and has significantly increased the sensitivity of the modified Duke criteria from 70% to 97% without affecting the specificity [34]. Recent meta-analysis showed that diagnostic accuracy with ^{18}F-FDG PET/CT for PVE was improved with sensitivity of 80.5% and specificity of 73.1% [35]. Additional extracardiac foci of infection were found on 17% of patients on whole body PET/CT [35]. In a systematic review Nuvoli et al. reported that sensitivity and specificity values of ^{18}F-FDG PET/CT ranged from 73% to 96.6% and from 80% to 94%, respectively [36]. False positive findings are possible due to reactive inflammatory activity in the early stage after prosthesis implantation, while the presence of minor vegetation or previous antibiotic therapy may cause false negative results [35–37]. ^{18}F-FDG PET/magnetic resonance imaging (MRI) has been recently proposed as an even better technique than PET/

Table 1
Strengths and limitations of the various imaging modalities in assessing prosthetic valve endocarditis.

	TTE	TEE	MSCT	PET/CT
Technical aspects				
Availability	++++	++++	+++	+
Cost	+	+	++	++++
Typical scan duration (min)	15–20	15–20	10–15	60
Safety	High	High	• Ionizing radiations	• Pregnancy
			• Potentially nephrotoxic contrast	• High ionizing radiations
			• Allergic reaction to contrast	• Potentially nephrotoxic contrast
				• Allergic reaction to contrast
Imaging window dependence	Present	Present	Absent	Absent
Sensitivity (%)	17–36	82–96	88–97	80–96
Specificity (%)	86	94	95	73–94
Diagnostic accuracy	Specific	Sensitive and specific	Sensitive and specific	Sensitive
Temporal resolution	+++	+++	++	+
Spatial resolution	+++	+++	++++	+
3D acquisition	No	Yes	Yes	No
Anatomic vs. functional data	Anatomic and functional	Anatomic	Detailed anatomic	Functional (molecular)
Major limitations	• Operator dependent	• Operator dependent	• Ionizing radiation	• Costs
	• Poor acquisition quality	• Possible artifacts	• Potentially nephrotoxic contrast	• Low availability
				• Low resolution (vegetations <5 mm not seen)
				• Physiological FDG uptake and nonspecific uptake by uninfected tissues
				• False positive response post-operative
				• False negative response after initiation of antimicrobial therapy

FDG, fluorodeoxyglucose; MSCT, multislice computed tomography; PET/CT, positron emission tomography–computed tomography; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.
+, low; ++, moderate; +++, high; ++++, very high.

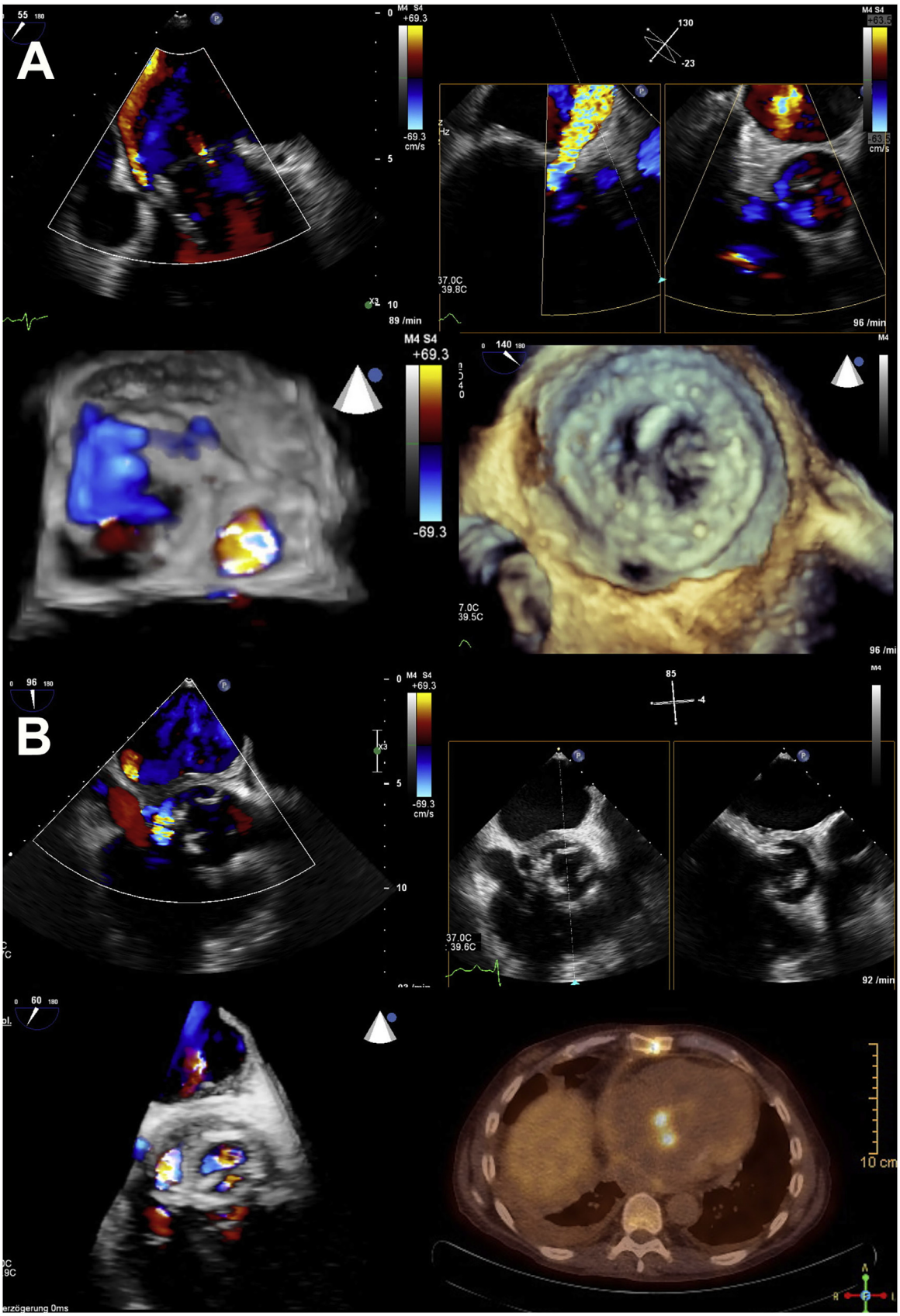

Fig. 1. Prosthetic valve endocarditis of biological aortic and mitral valve. (A) Paravalvular mitral leakage in 2D transesophageal echocardiography (first row) and 3D transesophageal echocardiography (second row). (B) Paravalvular aortic leakage and dehiscence (first row) and 3D paravalvular jet and positron emission tomography/computed tomography (second row).

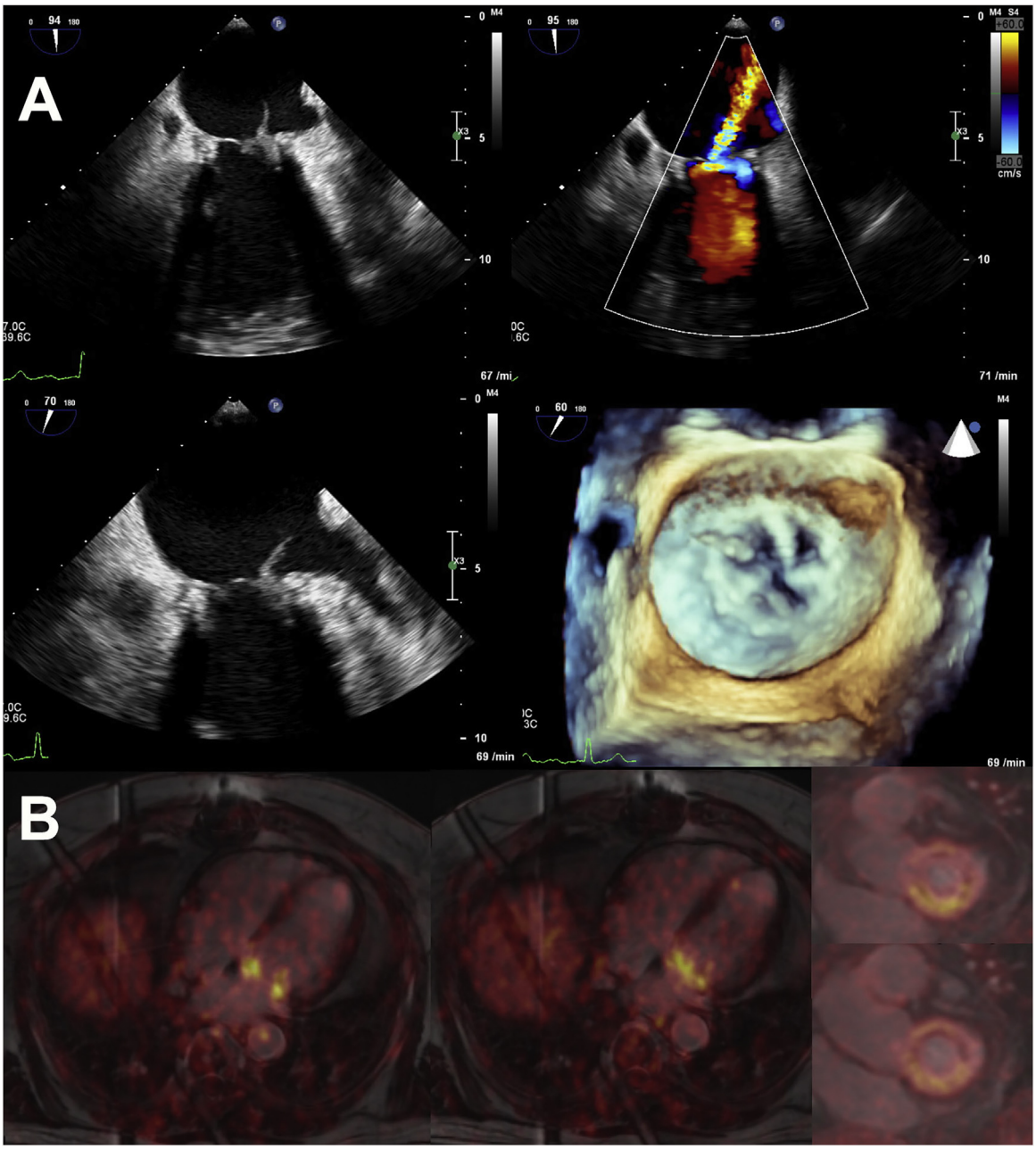

Fig. 2. Prosthetic valve endocarditis of the biological mitral valve with vegetation. (A) Vegetation on the biological prosthesis (leaflet) in 2D and 3D transesophageal echocardiography with significant mitral insufficiency. (B) Positron emission tomography/magnetic resonance imaging showing inflammation of the biological prosthetic mitral valve.

CT because of its significantly better special resolution. However, data regarding this topic are still scarce. Figs. 1–3 represent several interesting cases from daily practice in which most of these techniques were used, but particularly TEE and PET/CT or PET-MRI.

Complications

The complications of PVE are multiple: persistently positive blood cultures, septic embolism, heart failure, as well as death [1]. Persistent infection and heart failure are the strongest predictive factors of in-hospital mortality in patients with prosthetic valve endocarditis. Although similar to those in patients with NVE, PVE complications are more difficult to treat.

The exact definition of persistent bacteremia or relapse represents a problem since duration of bacteremia depends on microorganism. Infection caused by *S. viridans* might become sterile even after 48 h, while in methicillin-resistant *S. aureus* (MRSA) bacteremia positive blood cultures might be found even after 7 days of appropriate treatment [38]. Septic embolism associated with PVE significantly increases mortality and morbidity. Similar to NVE it may manifest as cerebral, splenic, or renal abscess. In the group of 111 patients with PVE the incidence of stroke was found to be 23%. Additionally, 42% of patients with PVE experienced hemorrhagic transformation, most likely secondary to anticoagulation therapy that is frequently given in these situations [39]. It has been reported that in early PVE the risk of spreading infection into myocardium is increased. It is also associated with perivalvular abscess which increases the risk of heart failure and mortality, in up to 55% of cases [40]. Partial or complete valve dehiscence represents a specific type of complication. A case of

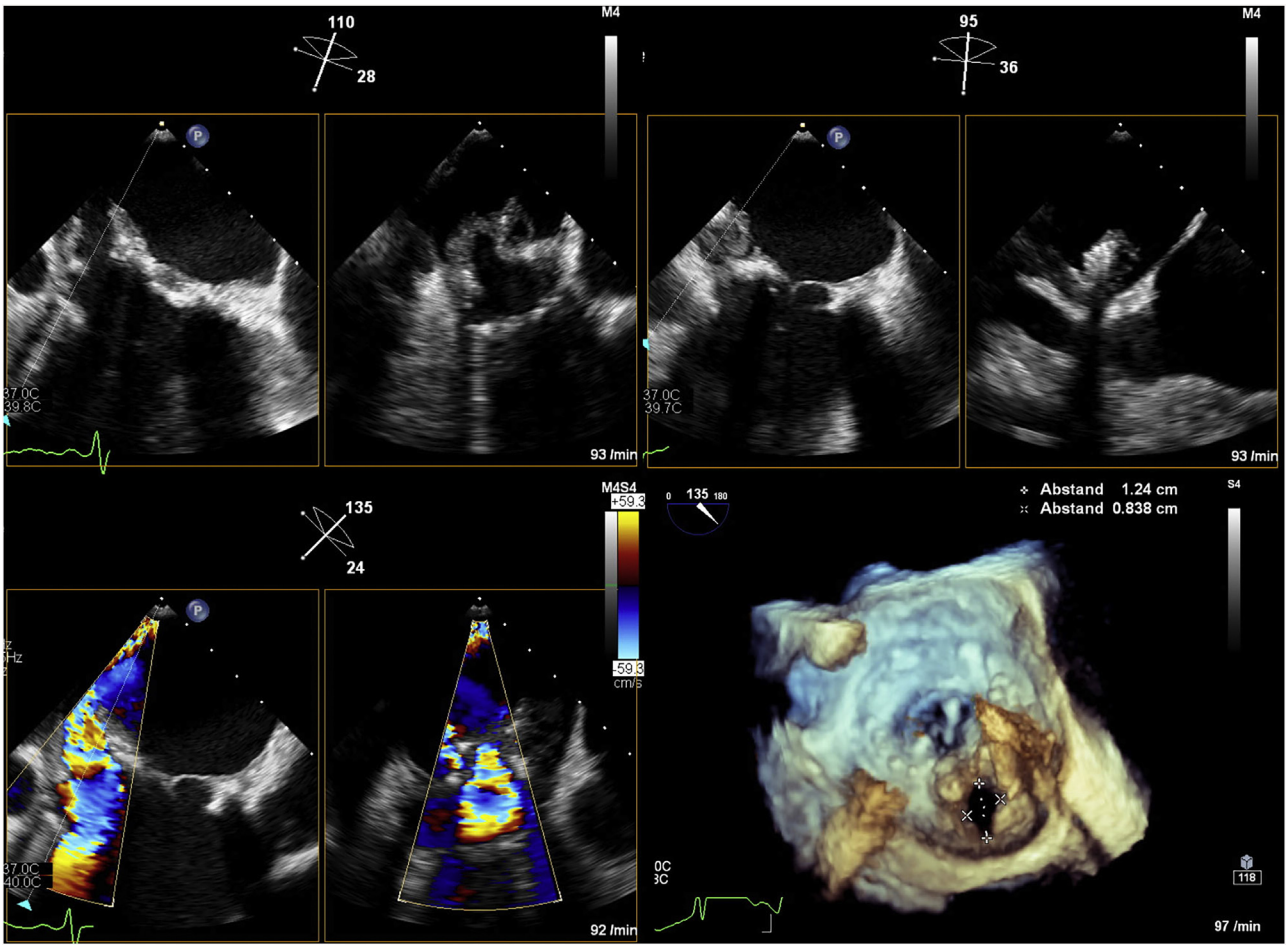

Fig. 3. Prosthetic valve endocarditis of the mitral valve with large dehiscence and paravalvular leakage (vegetation with thrombus partly covering large dehiscence) detected by (2D and 3D transesophageal echocardiography).

early staphylococcal PVE associated with mechanical valve dislocation into sinotubular junction has been reported [41]. Heart failure is the most common complication of PVE with the incidence up to 56% and one of the most important predictors of intra-hospital mortality [42].

Prognosis and treatment

Fariñas et al. investigated risk factors for development of PVE and found significant correlation between PVE and heart failure New York Heart Association class III and IV, previous IE, alcohol abuse, and fever in patients in intensive care unit with gastrointestinal bleeding [43]. Poor outcome of PVE is related to multiple factors such as older age, diabetes mellitus, healthcare-associated infections, staphylococcal and fungal infections, early postoperative development of PVE, heart failure, stroke, and intracardiac abscess [32]. These patients need more aggressive treatment which usually includes surgery in addition to antibiotic therapy. Luciani et al. showed that female gender, shock status, previous surgical procedures within 3 months from the treatment, multivalvular involvement, abscess, and urgent surgery were independent predictors of short-term (30-day) mortality in PVE patients [8].

Meta-analysis that included 10,754 IE patients (6776 biological valves and 3978 mechanical valves) showed that the all-cause mortality risk of the biological valve group was higher than that of the mechanical valve group [hazard ratio (HR) = 1.22, $p = 0.023$] [12]. The recurrence of IE (HR = 1.75, $p = 0.001$), as well as the risk of reoperation (HR = 1.79, $p = 0.010$), was significantly higher in the patients with biological valves. For the patients with PVE, there was no significant difference in survival rates between the biological valve group and the mechanical valve group.

All above-mentioned complications – heart failure, large vegetation with high embolization risk and risk for valvular obstruction and development of acute heart failure, abscess formation, persistently positive blood cultures, staphylococcal and fungal bacteremia – are indications for surgical treatment. Benefits of early surgical interventions from clinical studies are controversial [44,45]. However, emergent redo surgery is required in case of refractory heart failure with risk of progression to acute pulmonary edema and cardiogenic shock [32]. The cornerstone of surgical treatment in patients with PVE is complete debridement of infected material and implantation of new valve in healthy tissue [46].

Perioperative mortality in mitral PVE is high – up to 13%, especially when it comes to surgical treatment of mitral perivalvular abscess which is extraordinarily challenging [47].

Early surgery is recommended in PVE patients with relapsing infection or large vegetation even in the absence of hemodynamic significant complications in the European and American guidelines [32,48]. However, it is unclear whether surgery in addition to antibiotics offers any benefit compared to antibiotic therapy alone. The mortality in patients treated only with antibiotics has been estimated to be 23–29%, while in those who underwent additional

surgical treatment it is 24–35% [49,50]. It drives the conclusion that a significant number of patients can be treated with antibiotic therapy alone, such as hemodynamic stable patients with PVE other then staphylococcal. Antibiotic treatment is similar to that given in patients with NVE, suggesting that patients with PVE need closer monitoring during the therapy and close follow up after completion of antibiotic treatment [51].

In 60% of patients with transcatheter valve replacement (aortic and pulmonary) management is achieved medically despite related complications such as local extension, embolism, and heart failure in more than 50% of patients [12]. The valve explantation rate was 57% and 23% in balloon- and self-expandable valves, respectively. In-hospital mortality was 34.4%. Most PVE patients after transcatheter pulmonary valve replacement (75%) were managed surgically, and in-hospital mortality was 7.1% [12]. Due to high operative risk in TAVI patients, IE in these patients is often treated conservatively, whereas only 12–45% of these patients received surgical treatment [51]. On the other hand, approximately two thirds of MitraClip patients with PVE underwent surgery [25]. In patients with significant comorbidities and expected poor postoperative recovery, i.e. those with high operative risk due to cardiomyopathy, neurological, or other specified condition or technical limitations due to previous surgery, redo intervention is discouraged [26].

Antibiotic prophylaxis is highly recommended in all patients with prosthetic valves, prosthetic materials used in reconstructive surgery, previous transcatheter valve replacement, or previous episode of IE [32].

Conclusion

PVE is a serious potential complication of valve replacement surgery with significant mortality. Establishing a diagnosis is not an easy task. Nowadays several imaging modalities with good ratio between sensitivity and specificity are available. However, echocardiography remains the first choice. The treatment of PVE is even more challenging because of PVE complexity and high-risk profile of these patients due to frequent comorbidities. Staphylococcal ethology, large vegetation with high embolization risk, paravalvular or myocardial abscess, fistula, valve dehiscence, and heart failure are reasons for prompt therapy with medical and often surgical approaches. Timing of surgery and type of cardiac valve are still a matter of debate. The introduction of transcatheter valve implantations and devices significantly changed the approach to PVE patients. Additional studies are necessary to define therapeutic strategies for this potentially fatal complication.

Conflict of interest

None.

References

[1] Habib G, Thuny F, Avierinos JF. Prosthetic valve endocarditis: current approach and therapeutic options. Prog Cardiovasc Dis 2008;50:274–81.
[2] Nataloni M, Pergolini M, Rescigno G, Mocchegiani R. Prosthetic valve endocarditis. J Cardiovasc Med (Hagerstown) 2010;11:869–83.
[3] Slaughter L, Morris JE, Starr A. Prosthetic valvular endocarditis. A 12-year review. Circulation 1973;47:1319–26.
[4] Østergaard L, Valeur N, Ihlemann N, Smerup MH, Bundgaard H, Gislason G, et al. Incidence and factors associated with infective endocarditis in patients undergoing left-sided heart valve replacement. Eur Heart J 2018;39:2668–75.
[5] Østergaard L, Valeur N, Ihlemann N, Bundgaard H, Gislason G, Torp-Pedersen C, et al. Incidence of infective endocarditis among patients considered at high risk. Eur Heart J 2018;39:623–9.
[6] Wilson WR, Jaumin PM, Danielson GK, Giuliani ER, Washington II JA, Geraci JE. Prosthetic valve endocarditis. Ann Intern Med 1975;82:751–6.
[7] Wang A, Athan E, Pappas PA. Contemporary clinical profile and outcome of prosthetic valve endocarditis. JAMA 2007;297:1354–61.
[8] Luciani N, Mossuto E, Ricci D, Luciani M, Russo M, Salsano A, et al. Prosthetic valve endocarditis: predictors of early outcome of surgical therapy. A multicentric study. Eur J Cardiothorac Surg 2017;52:768–74.
[9] Brennan JM, Edwards FH, Zhao Y, O'Brien S, Booth ME, Dokholyan RS, et al. Long-term safety and effectiveness of mechanical versus biologic aortic valve prostheses in older patients: results from the Society of Thoracic Surgeons Adult Cardiac Surgery National Database. Circulation 2013;127:1647–55.
[10] Hammermeister KE, Sethi GK, Henderson WG, Oprian C, Kim T, Rahimtoola S. A comparison of outcomes in men 11 years after heart-valve replacement with a mechanical valve or bioprosthesis. Veterans Affairs Cooperative Study on Valvular Heart Disease. N Engl J Med 1993;328:1289–96.
[11] Bloomfield P, Wheatley DJ, Prescott RJ, Miller HC. Twelve-year comparison of a Bjork–Shiley mechanical heart valve with porcine bioprostheses. N Engl J Med 1991;324:573–9.
[12] Tao E, Wan L, Wang W, Luo Y, Zeng J, Wu X. The prognosis of infective endocarditis treated with biological valves versus mechanical valves: a meta-analysis. PLoS One 2017;12:e0174519.
[13] Grover FL, Cohen DJ, Oprian C. Determinants of the occurrence of and survival from prosthetic valve endocarditis. Experience of the veterans affairs cooperative study on valvular heart disease. J Thorac Cardiovasc Surg 1994;108:207.
[14] Rutledge R, Kim BJ, Applebaum RE. Actuarial analysis of the risk of prosthetic valve endocarditis in 1,598 patients with mechanical and bioprosthetic valves. Arch Surg 1985;120:469.
[15] Chu VH, Miro JM, Hoen B. Coagulase-negative staphylococcal prosthetic valve endocarditis – a contemporary update based on the International Collaboration on Endocarditis: prospective cohort study. Heart 2009;95:570.
[16] Lopez J, Revilla A, Vilacosta I, Villacorta E, Gonzalez- Juanatey C, et al. Definition, clinical profile, microbiological spectrum, and prognostic factors of early-onset prosthetic valve endocarditis. Eur Heart J 2007;28:760–5.
[17] Tan HL, Chai LY, Yeo TC, Chia BL, Tambyah PA, Poh KK. Predictors of in-hospital adverse events in patients with prosthetic valve infective endocarditis. Heart Lung Circ 2015;24:705–9.
[18] Rivoisy C, Vena A, Schaeffer L, Charlier C, Fontanet A, Delahaye F, et al. Prosthetic valve Candida spp. endocarditis: new insights into long-term prognosis – The ESCAPE study. Clin Infect Dis 2018;66:825–32.
[19] Falcone M, Barzaghi N, Carosi G. Candida infective endocarditis: report of 15 cases from a prospective multicenter study. Medicine 2009;88:160–8.
[20] Akinosoglou K, Apostolakis E, Koutsogiannis N, Leivaditis V, Gogos CA. Right-sided infective endocarditis: surgical management. Eur J Cardiothorac Surg 2012;42:470–9.
[21] Hussain ST, Shrestha NK, Witten J, Gordon SM, Houghtaling PL, Tingleff J, et al. Rarity of invasiveness in right-sided infective endocarditis. J Thorac Cardiovasc Surg 2018;155:54–61.
[22] Amat-Santos IJ, Ribeiro HB, Urena M, Allende R, Houde C, Bedard Perron J, et al. Prosthetic valve endocarditis after transcatheter valve replacement. JACC Cardiovasc Interv 2015;8:334–46.
[23] Regueiro A, Linke A, Latib L. Association between transcatheter aortic valve replacement and subsequent infective endocarditis and in-hospital death. JAMA 2016;316:1083–92.
[24] Eggebrecht H, Schelle S, Puls M, Plicht B, von Bardeleben RS, Butter C, et al. Risk and outcomes of complications during and after MitraClip implantation: experience in 828 patients from the German TRAnscatheter mitral valve interventions (TRAMI) registry. Catheter Cardiovasc Interv 2015;86:728–35.
[25] Boeder NF, Dörr O, Rixe J, Weipert K, Bauer T, Bayer M, et al. Endocarditis after interventional repair of the mitral valve: review of a dilemma. Cardiovasc Revasc Med 2017;18:141–4.
[26] Nagpal A, Sohail MR, Steckelberg JM. Prosthetic valve endocarditis: state of the heart. Clin Invest 2012;2:803–17.
[27] Gomes A, Glaudemans AWJM, Touw DJ, van Melle JP, Willems TP, Maass AH, et al. Diagnostic value of imaging in infective endocarditis: a systematic review. Lancet Infect Dis 2017;17:e1–4.
[28] Vered Z, Mossinson D, Peleg E. Echocardiographic assessment of prosthetic valve endocarditis. Eur Heart J 1995;16(Suppl. B):63.
[29] Daniel WG, Mügge A, Grote J. Comparison of transthoracic and transesophageal echocardiography for detection of abnormalities of prosthetic and bioprosthetic valves in the mitral and aortic positions. Am J Cardiol 1993;71:210.
[30] Morguet AJ, Werner GS, Andreas S, Kreuzer H. Diagnostic value of transesophageal compared with transthoracic echocardiography in suspected prosthetic valve endocarditis. Herz 1995;20:390.
[31] Sochowski RA, Chan KL. Implication of negative results on a monoplane transesophageal echocardiographic study in patients with suspected infective endocarditis. J Am Coll Cardiol 1993;21:216.
[32] Habib G, Lancellotti P, Antunes MJ, Bongiorni MG, Casalta J-P, Del Zotti F, et al. 2015 ESC Guidelines for the management of infective endocarditis: The Task Force for the Management of Infective Endocarditis of the European Society of Cardiology (ESC), Endorsed by: European Association for Cardio-Thoracic Surgery (EACTS), the European Association of Nuclear Medicine (EANM). Eur Heart J 2015;36:3075–128.
[33] Bruun NE, Habib G, Thuny F, Sogaard P. Cardiac imaging in infectious endocarditis. Eur Heart J 2014;35:624–32.
[34] Saby L, Laas O, Habib G. Positron emission tomography/computed tomography for diagnosis of prosthetic valve endocarditis: increased valvular 18F-fluorodeoxyglucose uptake as a novel major criterion. J Am Coll Cardiol 2013;61:2374–82.
[35] Mahmood M, Kendi AT, Ajmal S, Farid S, O'Horo JC, Chareonthaitawee P, et al. Meta-analysis of 18F-FDG PET/CT in the diagnosis of infective endocarditis. J Nucl Cardiol 2017. http://dx.doi.org/10.1007/s12350-017-1092-8 [Epub ahead of print].

[36] Nuvoli S, Fiore V, Babudieri S, Galassi S, Bagella P, Solinas P, et al. The additional role of 18F-FDG PET/CT in prosthetic valve endocarditis. Eur Rev Med Pharmacol Sci 2018;22:1744–51.
[37] Chen W, Kim J, Molchanova-Cook OP, Dilsizian V. The potential of FDG PET/CT for early diagnosis of cardiac device and prosthetic valve infection before morphologic damages ensue. Curr Cardiol Rep 2014;16:459–66.
[38] Levine DP, Fromm BS, Reddy BR. Slow response to vancomycin or vancomycin plus rifampin in methicillin-resistant *Staphylococcus aureus* endocarditis. Ann Int Med 1991;115:674–80.
[39] Cho IJ, Kim JS, Chang HJ, Kim YJ, Lee SC. Prediction of hemorrhagic transformation following embolic stroke in patients with prosthetic valve endocarditis. J Cardiovasc Ultrasound 2013;21:123–9.
[40] Kuyvenhoven JP, van Rijk-Zwikker GL, HermansJ, Thompson J, Huysmans HA. Prosthetic valve endocarditis: analysis of risk factors for mortality. Eur J Cardiothorac Surg 1994;8:420–4.
[41] Krishna RK, Casanova P, Larrauri-Reyes M, Santana O. Complete dehiscence and unseated prosthetic aortic valve causing severe aortic insufficiency: an unusual complication of prosthetic valve endocarditis. Case Rep 2014;25. bcr2014206925-bcr.
[42] López J, Sevilla T, Vilacosta I, García H, Sarriá C. Clinical significance of congestive heart failure in prosthetic valve endocarditis. A multicenter study with 257 patients. Rev Esp Cardiol (Engl Ed) 2013;66:384–90.
[43] Fariñas CM, Pérez-Vázquez A, Fariñas-Álvarez C, García-Palomo DJ, Bernal JM, Revuelta JM, et al. Risk factors of prosthetic valve endocarditis: a case–control study. Ann Thorac Surg 2006;81:1284–90.
[44] Lalani T, Chu VH, Park LP, Cecchi E, Corey GR, Durante-Mangoni E, et al. In-hospital and 1-year mortality in patients undergoing early surgery for prosthetic valve endocarditis. JAMA Intern Med 2013;173:1495–504.
[45] Kiefer T, Park L, Tribouilloy C, Cortes C, Casillo R, Chu V, et al. Association between valvular surgery and mortality among patients with infective endocarditis complicated by heart failure. JAMA 2011;306:2239–47.
[46] d'Udekem Y, David TE, Feindel CM, Armstrong S, Sun Z. Long-term results of operation for paravalvular abscess. Ann Thorac Surg 1996;62:48–53.
[47] Greason KL, Thomas M, Steckelberg JM, Daly RC, Schaff HV. Outcomes of surgery in the treatment of isolated nonnative mitral valve infective endocarditis. J Thorac Cardiovasc Surg 2014;147:349–54.
[48] Infective endocarditis in adults: diagnosis, antimicrobial therapy, and management of complications: a scientific statement for healthcare professionals from the American Heart Association. Circulation 2015;132:1435–86.
[49] Akowuah EF, Davies W, Oliver S, Stephens J, Riaz I. Prosthetic valve endocarditis: early and late outcome following medical or surgical treatment. Heart 2003;89:269–72.
[50] Truninger K, Attenhofer Jost CH, Seifert B, Vogt PR, Follath F. Long term follow up of prosthetic valve endocarditis: what characteristics identify patients who were treated successfully with antibiotics alone? Heart 1999;82:714–20.
[51] Chourdakis E, Koniari I, Hahalis G, Kounis NG, Hauptmann KE. Endocarditis after transcatheter aortic valve implantation: a current assessment. J Geriatr Cardiol 2018;15:61–5.