Infective endocarditis: Perioperative management and surgical principles

Kareem Bedeir, MBChB, MS, Michael Reardon, MD, and Basel Ramlawi, MD, MMSc, FRCSC, FACS, FACC

Despite advances in microbial prevention and elimination, the frequency of endocardial infection is still increasing and it remains to be a serious condition. The strategies and aggressiveness of medical and surgical algorithms for managing these patients are evolving and having a significant effect on morbidity and mortality. This review addresses the current understanding of the processes by which the most common and most threatening complications occur, and the current management strategies that cardiologists and cardiac surgeons should be aware of when treating these seriously ill patients. (J Thorac Cardiovasc Surg 2014;147:1133-41)

Despite major advances in diagnostic modalities and antimicrobial therapies, infective endocarditis (IE) remains an extremely ominous infection, with a 1-year mortality rate of up to 40%.^{1,2} Management of these critically ill patients requires an understanding of the disease process in its various microbial, hemodynamic, embolic, and immunologic forms. At the time of diagnosis, patients have often progressed to complications through 1 aspect of the disease. An appreciation of the spectrum of the disease processes is crucial for providing a timely and effective intervention. In this article, the processes by which the most common and most threatening complications occur, as well as what every physician ought to know when treating these seriously ill patients are discussed.

OVERVIEW OF COMPLICATIONS

After bacteria seed the endocardium, erosions into various cardiac structures take place through an interplay of direct bacterial invasion, enhanced inflammatory response, and liquefactive enzyme release within cardiac tissues. This is particularly pronounced in IE caused by *Staphylococcus aureus*, especially in the aortic valve position. This is probably due to the less annular fibrous tissue support in the aortic position compared with the mitral position. Unfortunately, IE tends to occur more frequently in the aortic valve than any other valve, and the frequency of *S aureus* as the cause of IE has increased dramatically over the past 2 decades, from 2% in 1990 to 25% in 2009.³

Congestive heart failure (CHF) through a sudden volume overload on the ventricles, whether caused by a sudden

regurgitant lesion or shunt creation, can complicate IE. Sudden regurgitation usually occurs as a result of chordal rupture in native valve endocarditis (NVE), a valve leaflet perforation in NVE or in bioprosthetic valve IE, or valve dehiscence in prosthetic valve endocarditis (PVE). In NVE and PVE, CHF is the complication with the greatest independent impact on prognosis whether medically or surgically treated.^{4,5} Early studies comparing antimicrobial therapy with surgery in patients with IE complicated by CHF demonstrated a clear superiority with surgery (23% vs 71% mortality rates).⁶⁻⁸ Much less commonly, heart failure can be obstructive in nature when large vegetation obstructs a heart chamber outflow.

A similar pathophysiology also leads to paraannular extension (PAE) of the infection. Given the similar pathophysiology, PAE is also more common with necrotizing organisms, and in the aortic position. In addition, PAE is one of the most frequent complications of IE, occurring in up to 100% of infected prosthetic valves and 40% of infected native valves.⁹ The infectious process around the valve weakens the annulus, and eventually leads to tissue destruction, valve dehiscence, abscess formation, and sometimes fistulization. This is associated with an increased occurrence of CHF and a higher mortality rate. A PAE-related fistula has been shown to lead to up to 40% mortality.^{10,11}

In addition to the local destruction that complicates IE, systemic embolization is the most common complication. Emboli usually consist of vegetations or friable necrotic and often infected tissues. Unlike local effects, this is more common in the mitral valve position. Although the embolic risk is high (embolic events occur in up to 50% of patients), this risk declines dramatically with initiation of antibiotic treatment, and even more after 2 weeks of effective continuation.^{3,12-14} The rate of systemic embolization is significantly higher in patients who have had a previous embolic event, those in the first 2 weeks of antibiotic therapy, those with left-sided IE especially in the mitral position, those with mobile vegetation that is large (10-15 mm) or increasing in size despite antibiotic therapy, and those patients infected with certain pathogens

From the Methodist DeBakey Heart & Vascular Center, Houston, Tex.

Disclosures: Dr Basel Ramlawi and Dr Michael Reardon are co-investigators in the Medtronic CoreValve trial. All other authors have nothing to disclose with regard to commercial support.

Received for publication July 17, 2013; revisions received Sept 30, 2013; accepted for publication Nov 12, 2013; available ahead of print Jan 13, 2014.

Address for reprints: Basel Ramlawi, MD, MMSc, FRCSC, FACS, FACC, Cardiovascular Surgery & Transplantation, Methodist DeBakey Heart & Vascular Center, 6550 Fannin St, Smith Tower - Suite 1401, Houston, TX 77030 (E-mail: bramlawi@tmhs.org).

0022-5223/\$36.00

Copyright © 2014 by The American Association for Thoracic Surgery

<http://dx.doi.org/10.1016/j.jtcvs.2013.11.022>

Abbreviations and Acronyms

ACC = American College of Cardiology
 CHF = congestive heart failure
 CT = computed tomography
 ESC = European Society of Cardiology
 GFP = glutaraldehyde-fixed pericardial
 IE = infective endocarditis
 MIC = minimum inhibitory concentration
 MRI = magnetic resonance imaging
 NVE = native valve endocarditis
 PAE = paraannular extension
 PVE = prosthetic valve endocarditis
 TEE = transesophageal echocardiography
 TTE = transthoracic echocardiography

(*S aureus*, fungi, enterococci, and HACEK).^{3,12,15} No vascular bed is immune, but 65% of these pathogens usually affect the brain, 90% in the middle cerebral artery territory. Renal and splenic vascular beds are also commonly involved.¹⁶ When a septic embolus reaches its target, it ends up causing an infarction, an abscess usually with *S aureus*, or rarely a mycotic aneurysm when the intramural vasa vasorum are involved. This is usually followed by wall attenuation and progressive aneurysmal dilatation of the affected vessel.

Less virulent organisms usually have a less pronounced local effect. An indolent subacute course triggers an antibody response that puts the patient at risk of immune complex glomerulonephritis. Acute renal failure complicates up to 30% of patients with IE and is associated with a poor prognosis. This is especially true when it is compounded by septic renal embolism, prerenal failure caused by CHF, and the nephrotoxic effects of gentamicin and vancomycin, commonly used in high doses for treating these patients.¹⁷

MAKING THE DIAGNOSIS

An accurate diagnosis is crucial. Missing a diagnosis likely leads to a poor outcome or death, and overdiagnosing patients leads to exposure to high doses of potentially toxic antimicrobials that are unnecessary. Several defining criteria have been proposed including those by Pelletier and Petersdorf¹⁸ and Von Reyn and colleagues¹⁹; however, the more recent Duke criteria and their revisions in 2000 seem to be the most widely used.^{20,21} Based on the latter, a diagnosis is made if any of the following is present: (1) pathologically tested tissue; (2) 2 major criteria; (3) 1 major plus 3 minor criteria; or (4) 5 minor criteria (Table 1). A high pretest probability justifies commencing treatment even if the diagnosis is not definite according to the criteria.

Cornerstone major criteria include blood cultures and echocardiographic findings. However, an accurate diagnosis is not always straightforward, given that 25% to 30% of patients in this era present with no previously known cardiac structural abnormality.²² This is in part due to the more acute rather than subacute disease process taking place with the increased prevalence of *S aureus* as a causative agent. An accurate diagnosis has been made even more difficult by increasing rates of culture-negative IE. In the United States, 79% of cases with culture-negative IE were found to be due to early administration of antimicrobials or faulty culturing technique, emphasizing their relative importance and how seemingly trivial details may alter or complicate the diagnosis.²³

Echocardiography should be done as soon as IE is suspected. The role of echocardiography goes beyond the diagnosis, and repeat echocardiography is recommended on clinical deterioration or when complications are suspected. Echocardiography guides the decision on whether to operate and when, as discussed later. However, the role of transthoracic echocardiography (TTE) in the assessment of left-sided IE is controversial, because of its significantly lower negative predictive values compared to transesophageal echocardiography (TEE).^{24,25} Although TEE has a near 100% negative predictive value with NVE, it is operator dependent and is far less sensitive for PVE and abscesses of the mitral valve associated with posterior annular calcification.^{3,26} In these situations, repeat TEE as well as a combination of TTE and TEE might mitigate the limitations caused by acoustic shadowing. Unfortunately, 15% of patients with proven IE were reported to have no echocardiographic findings.²⁷

STARTING MANAGEMENT

Managing a patient with IE aims at 2 goals: eradication of infection and restoration of cardiac structures. Eradicating infection, whether medically or surgically, should abort the disease process, and thus prevent further local, hemodynamic, immunologic, or embolic complications. Structural restoration is primarily surgical and is aimed at repairing the damaged tissue in which healing would not be sufficient, and would otherwise have short-term or long-term hemodynamic implications.

Once the diagnosis of IE is suspected, at least 3 sets of blood culture samples should be drawn from different sites and at 30-minute intervals.^{28,29} This should be followed immediately by initiation of intravenous empirical antibiotic therapy as shown in Table 2. With no justification for delay, this empirical therapy should be qualitatively bactericidal and quantitatively in high doses for up to 6 weeks. Selecting the best antibiotic for a particular patient should be guided by the presence or absence of previous antibiotic use, whether this is a suspected case of NVE,

TABLE 1. Major and minor revised Duke criteria

Major	Minor
Persistent positive blood culture with typical infective endocarditis microorganism	Predisposing factor: known cardiac lesion, recreational drug injection
Evidence of endocardial involvement with echocardiogram	Fever >38°C
	Evidence of embolism
	Immunologic problems
	Positive blood culture (that does not meet a major criterion)

early PVE or late PVE, and by consultation with the microbiological team regarding epidemiologic clues for pathogen trends and antibiotic resistance at that specific area or facility. A list of generally encountered epidemiologic clues that might guide antibiotic selection has been published previously.³⁰

In general, the nature and pathogenesis of early PVE is different from other forms of IE. NVE and late PVE usually occur with distant blood stream pathogen access, which eventually leads to pathogen adherence at a point in the heart that has been previously predisposed, whether by disease causing a jet and Venturi effect on the low-pressure side or by an implanted prosthesis. On the other hand, early PVE is mostly caused by microbes that can adhere to the annulus-ring interface and to the perivalvular suture pathways when they are coated with fibronectin and fibrinogen before endothelialization takes place. Inoculation typically takes place within the first 60 days after surgery and is usually nosocomial. After this period, and up to 12 months, there is a transition in pathogenesis and causative organisms that ends with complete endothelialization. The mechanism, the microbiology, and the incidence of PVE beyond 12 months are similar to NVE.

Both the American Heart Association (AHA)/American College of Cardiology (ACC) and the European Society of Cardiology (ESC) guidelines regard gentamicin as an optional addition to initial combination therapy, because of its presumed synergistic effect with cell-wall inhibitors. The ESC guidelines, however, recommend it for PVE.^{3,28} A valid argument against gentamicin has been proposed, given its proven renal toxicity against the background of doubtful benefit.^{31,32} These studies recommended the

TABLE 2. Empirical antimicrobial therapy with early PVE, late PVE, and NVE

Early PVE (<12 months after surgery)	NVE and late PVE (≥12 months after surgery)
Vancomycin plus rifampin (± gentamicin)	Combination penicillins (ampicillin-sulbactam and amoxicillin-clavulanate) (± gentamicin)
	If intolerant to penicillins: vancomycin plus ciprofloxacin (± gentamicin)

use of daptomycin as a noninferior option for proven staphylococcal infection rather than standard therapy including gentamicin. However, the impact of gentamicin on creatinine clearance did not seem to lead to dialysis or otherwise adversely affect the patients' course in these studies.

With the exception of staphylococcal infections, fever should resolve within a few days after starting therapy, and all patients should have surveillance blood cultures after 3 to 4 days of intravenous drug therapy. In a significant number of patients, cultures are negative, and this should never rule out IE. As mentioned earlier, previous antibiotic use is a common reason why cultures are not positive. Also slow-growing or atypical organisms (Q-fever and *Bartonella*) and fungal infection might be present.^{30,33}

MODIFYING THERAPY

In most true cases of IE, blood cultures are positive and therapy should be modified accordingly. Lists of different drug regimens, doses, combinations, and durations of therapy for cultured organisms have been published previously.^{3,30} Medical regimens should not be modified based only on qualitative microbial sensitivity. Minimum inhibitory concentrations (MIC) of specific drugs for specific pathogens should be followed. For example, *S aureus* exists in strains that are vancomycin intolerant and stop growing in the presence of the drug rather than die. These strains resurge after the treatment stops. Moreover, the high trough levels of vancomycin that are necessary for this growth inhibition are also enough to cripple the patient's renal function. In this situation, the MIC should guide the substitution of vancomycin with less nephrotoxic alternatives such as daptomycin or teicoplanin.^{32,34}

Generally, antimicrobial combinations are preferred over monotherapy. This increases efficacy, reduces required drug doses and thus adverse effects, reduces the emergence of resistant strains, and shortens the duration of therapy. Aminoglycosides synergize with β -lactams and glycopeptides, and slow-growing or dormant pathogens residing within vegetation or biofilms justify the need for rifampicin for prolonged duration.³

CLOSE MONITORING

While antibiotic therapy is continued, close monitoring for treatment effectiveness and disease progression is key to the success of treatment. Fever and various indicators of ongoing inflammation have to be followed attentively, renal function and other side effects of the drugs should be anticipated, and complications of disease progression should be vigorously dealt with. The importance of close monitoring should be emphasized to allow for effective modifications of therapy and timely surgical intervention.

As previously described, CHF is the most common and the most ominous complication of IE, and must be treated aggressively. It is an AHA/ACC and ESC class I indication for surgery in patients with IE.^{3,28} The status of the infection should be completely disregarded when there is any evidence of hemodynamic instability or pulmonary edema, and surgical delay beyond 24 hours is not acceptable. In hemodynamically stable patients, urgent surgery should be performed when there are echocardiographic features of poor hemodynamic tolerance.³ With mitral valve IE, evidence of severe mitral regurgitation, including a rapidly decelerating late systolic transmitral signal (V-wave cut-off Doppler sign) as a result of markedly increased left atrial pressure or a finding of moderate to severe pulmonary hypertension, are signs of impending CHF. With aortic valve IE, premature closure of the mitral valve is an early sign of an overfilling left ventricle. These features should be specifically looked for, and emphasize the importance of repeat echocardiography when monitoring patients with known IE. In patients with mild CHF who are responding favorably to medical therapy, afterload reduction may be adopted with strict clinical and echocardiographic monitoring, while having the patient and the facility ready for urgent surgery.

A ruptured sinus of Valsalva into a heart chamber or into the pericardium is a complication that should be treated with similar urgency with a delay in surgery of no more than 24 hours. Otherwise, the indications for surgery are less clear and the decision and timing of surgical intervention is a difficult balance between the need to optimize the patient's medical condition and the fact that these patients are often extremely unwell and can deteriorate irreversibly at any moment. Generally, fungal, staphylococcal, or gram-negative endocarditis is almost always a surgical disease. PVE and device-related (pacemaker or implantable cardioverter defibrillator) endocarditis, a steeply increasing type of IE, should have a much lower threshold for surgery compared with NVE. On the other hand, right-sided endocarditis should have a higher threshold for surgery, and should primarily be considered a medical disease with some exceptions. In any case, consultation between the cardiologist and the cardiac surgeon should take place, and the patient with PVE should be taken off coumadin and aspirin, with heparin infusion replacement.

When fever and inflammatory mediators are persistently high despite adequate doses of appropriate antibiotic treatment, PAE has to be suspected. With any degree of unexplained heart block noted, abscess formation is likely. In both situations, TEE should be ordered immediately. An annular or aortic abscess, a new heart block, or valve dehiscence are considered class I indications for surgery.^{11,28} However, some investigators argue that nonresolving fever and increased inflammatory mediators despite 1 week of antibiotic therapy, together with positive surveillance blood cultures, should suffice for making the

decision on surgery.³⁵ In the case of shunt caused by IE and its high mortality rate, surgical intervention should be always performed, even in the absence of any evidence of heart failure.¹¹ In a few selected cases, medical therapy alone would be accepted in the context of confirmation of PAE. This can be the case when the isolated organism is sensitive, there is no evidence of valve destruction or heart block, and when abscesses are less than 1 cm in size. Otherwise, surgery should not be delayed.³⁵

Because of the relatively high rate of embolism in the first 2 weeks after diagnosis, patients at high risk of embolization should be identified, given that early surgery would potentially be more beneficial in these patients. As described earlier, with left-sided and especially mitral valve IE (anterior leaflet in particular), timely surgery might save patients who have had previous embolism and infections caused by certain organisms from disabling embolic events. The decision of surgery based on vegetation criteria alone is still controversial. The 2006 ACC/AHA guidelines recommend surgery as a class IIa indication only for those with recurrent emboli and persistent vegetation after antibiotic therapy.³³ The 2009 ESC guidelines recommend urgent surgery as a class IIb indication for vegetation greater than 15 mm in diameter.³ A recent randomized controlled study has clarified this gray zone regarding the impact of early surgery on embolic events. Kang and colleagues³⁶ randomized patients with left-sided IE and vegetation greater than 10 mm to either conventional early antibiotic treatment or surgery within 48 hours of randomization. Early surgery showed a significantly reduced composite end point of death from any cause and embolic events by effectively decreasing the risk of systemic embolism.

For patients who have already had a neurologic event, surgery is not contraindicated after transient ischemic attacks or ischemic (nonhemorrhagic) strokes. Although some controversy exists around the exact time frame for surgery after the event, in consensus, surgery should not be delayed after a nonhemorrhagic stroke in the presence of heart failure, PAE, ongoing sepsis, or persistent high embolic risk.³⁷ A computed tomography (CT) scan should be done on the brain before surgery to exclude the possibility of a hemorrhagic stroke. In the extremely unfortunate situation with an emergency indication of surgery in the setting of a hemorrhagic stroke, limited data are available and poor outcomes are expected with either conservative or operative management. In this situation, a wise decision should be made weighing the benefits and risks depending on the extent of hemorrhage, duration since onset, and association with neurologic deficit on the one hand, and the degree of hemodynamic compromise, the response to antimicrobial therapy, the anticipated complexity of surgery, and thus the anticipated cardiopulmonary bypass time on the other hand. On the contrary, recurrent pulmonary embolization in right-sided IE is not considered an

TABLE 3. Potential complications of infective endocarditis and the recommended approaches for management

Complication		Management	
Congestive heart failure (clinical or echocardiographic)		Surgery within 24 h, regardless of the status of the infection	
Paraannular extension	Ruptured sinus of Valsalva	In the absence of congestive heart failure, stabilizing the patient and controlling the infectious process medically should be attempted first. Surgery will be required eventually for structural restoration	
	Abscess		
	Conduction block		
	Prosthetic valve dehiscence		
Embolization	Cerebral	Hemorrhagic stroke should be excluded first.	Result from a recent randomized controlled trial
		Ischemic stroke does not preclude emergency or urgent surgery for hemodynamic and infectious complications of infective endocarditis	show superior outcomes with surgery within 48 h for left-sided infective endocarditis with vegetation >10 mm
	Splenic	Differentiation between infarcts and abscesses is crucial. Infarcts should be conservatively managed whereas abscesses will fail conservative trials and warrant splenectomy after stabilizing the patient. The splenic abscess should be addressed before any prosthetic valves, patches, or grafts are placed in the heart	
	Renal	Multifaceted medical management should be initiated to address renal ischemia, immune glomerulonephritis, as well as modification of antimicrobial therapy type or dose	
	Right-sided (pulmonary)	In the abscess of lung abscess, conservative management is recommended	

indication for surgery in the absence of pulmonary abscesses.³⁸

Splenic infarctions are common (44%) and usually improve with medical therapy alone, but splenic abscesses, which are not easily differentiated from infarcts are not expected to improve with medical therapy. Abdominal CT scan and magnetic resonance imaging (MRI) should be correlated with a high index of suspicion with poor clinical response to ongoing antibiotic therapy, and once a splenic abscess is diagnosed, a splenectomy is warranted as soon as the patient’s clinical status permits.¹³ The management is highly individualized, however, it is crucial to remove the spleen, whether by open or laparoscopic surgery, because it is a source of ongoing sepsis, before operating on the heart; otherwise, prosthetic grafts or valves will likely get infected.³⁹ If the patient’s clinical status necessitates urgent or emergency cardiac restoration surgery, concomitant splenectomy should be done if the patient is expected to tolerate such a procedure, otherwise immediate percutaneous aspiration of splenic abscesses is reasonable, followed by immediate cardiac surgery.¹³

The situation with poor clinical and inflammatory improvement with adequate and appropriate antibiotic therapy can be less straightforward. When abdominal CT or MRI scans are negative for abscesses, an alternative focus should be searched for. This can be difficult, and entails a detailed history for implants, orthopedic or any

other hardware, as well as a thorough physical examination including a dental examination. When no septic focus is found, we believe that a positron emission tomography/CT scan is a reasonable modality to accurately identify a hypermetabolic infected site.⁴⁰⁻⁴² As with splenic abscesses, the septic focus should be dealt with before or at the same time as implanting any prosthetic valves, patches, or grafts in the heart (Table 3).

OPERATING

Approximately half of patients with IE require surgery. Surgery for IE revolves around eradicating infection and debriding all necrotic tissue, with subsequent reconstruction of the cardiac chambers and valves. The reconstructive material should ideally provide durability and a low reinfection rate. Achieving these goals can be technically challenging at times. Repairs generally tend to be more complex and technically difficult when the infection spreads beyond the annulus. To a great extent, this is proportional to the virulence of the organism. Every effort should be made to avoid implanting a prosthesis. In some cases, implanting a prosthesis becomes inevitable because of extensive tissue destruction, and bioprostheses are always preferred over mechanical valves, and homografts and stentless valves may provide valvular support when the perivalvular tissue is extensively destroyed.^{43,44} The use of antibiotic-impregnated fibrin glue has been proposed to seal prosthetic valve sewing cuffs as well as abscess cavities.^{45,46} This is

FIGURE 1. Less extensive aorto-mitral curtain involvement can allow for primary or pericardial patch repair. A-C, Steps as labeled in the diagram. (Reprinted with permission from Ramlawi B, Reardon MJ. Endocarditis with involvement of the aorto-mitral curtain. *Op Tech Thorac Cardiovasc Surg.* 2011;16:242-9.)

largely based on in vitro studies showing a decreased infection rate using antibiotic-impregnated fibrin glue compared with antibiotic alone, fibrin glue alone, or saline.⁴⁷ However, comparative studies in humans are lacking.

Especially with mitral valve IE, every attempt should be made to repair. Reparability ranges between 34% and 80% in different reports.⁴⁸⁻⁵¹ The feasibility of repair seems be highest with either early active disease or with healed disease as an elective procedure. The former emphasizes the importance of prompt surgery with the earliest echocardiographic signs of decompensation with

regurgitant lesions. Even with more advanced active IE with extensive leaflet destruction, repair should be attempted first.

Annuloplasty, as with all mitral regurgitation repairs, is recommended. With IE, the outcomes after autologous glutaraldehyde-fixed pericardial (GFP) annuloplasty are effective and durable.⁵² Leaflet repair is always preferred over valve replacement, and excellent results have been reported. Zegdi and colleagues⁵³ reported a 10-year freedom from mitral reoperation of 91% using the Carpentier techniques in mitral valve endocarditis repair. Preservation

FIGURE 2. With more extensive aorto-mitral curtain involvement, adequate eradication of infection might require the removal of the entire aortic root, with reconstruction using an aortic root allograft with retained anterior mitral leaflet together with coronary reimplantation. A-D, Steps as labeled in the diagram. (Reprinted with permission from Ramlawi B, Reardon MJ. Endocarditis with involvement of the aorto-mitral curtain. *Op Tech Thorac Cardiovasc Surg*. 2011;16:242-9.)

of the left ventricular structure as well as the subvalvular apparatus might partly explain why repair can be better tolerated than replacement in the setting of CHF. Other

studies have also reported favorable results and lower rates of reinfection with repair.^{48,50,54,55} With extensive bileaflet destruction, a GFP fashioned leaflet can be attempted,

however, success rates and variations in durability are significant for different institutions and surgeons with mitral valve expertise. Total mitral valve homografts should be the last resort, given their technical difficulty as well as their less than optimal durability and high rates of reoperation.^{56,57}

In contrast to the mitral position, aortic valve IE that requires surgery usually requires valve replacement. Homografts seem to be the best option, given the increased tendency of aortic valve infections to extend beyond the annulus. This is also the case with PVE, for which significant tissue debridement is necessary.^{58,59} Infections extending into the left fibrous trigone or aorto-mitral curtain can pose a challenge. Less extensive lesions can be repaired primarily or using a GFP patch, however more extensive lesions require extensive debridement and total en-bloc replacement using an aorto-mitral homograft (Figures 1 and 2).⁶⁰ The Ross procedure is an option, although not many surgeons would achieve acceptable results.

Right-sided IE less commonly requires surgery. Tricuspid valve excision has been advocated in intravenous drug users with a high incidence of recurrence of tricuspid valve infection, but this was followed by unacceptable severe right-sided heart failure, and thus, this approach is no longer recommended. Bioprostheses seem to offer better results at the cost of higher chances of reinfection, especially with continued drug abuse.⁶¹

The duration of therapy should be based on the first day of effective antibiotic therapy, not on the day of surgery, if surgery took place. A new full antimicrobial course is only started after surgery if valve cultures are positive, and in this case, the choice of antibiotic should be modified accordingly.³ With PVE and device-related IE, prolonged antibiotic therapy is recommended for at least 6 weeks, and a new device should not be implanted except when complete microbiological eradication is achieved.³

References

- Hoen B, Alla F, Selton-Suty C, Beguinot I, Bouvet A, Briancon S, et al. Changing profile of infective endocarditis: results of a 1-year survey in France. *JAMA*. 2002;288:75-81.
- Wallace SM, Walton BI, Kharbanda RK, Hardy R, Wilson AP, Swanton RH. Mortality from infective endocarditis: clinical predictors of outcome. *Heart*. 2002;88:53-60.
- Habib G, Hoen B, Tornos P, Thuny F, Prendergast B, Vilacosta I, et al. Guidelines on the prevention, diagnosis, and treatment of infective endocarditis (new version 2009): the Task Force on the Prevention, Diagnosis, and Treatment of Infective Endocarditis of the European Society of Cardiology (ESC). Endorsed by the European Society of Clinical Microbiology and Infectious Diseases (ESCMID) and the International Society of Chemotherapy (ISC) for Infection and Cancer. *Eur Heart J*. 2009;30:2369-413.
- Hasbun R, Vikram HR, Barakat LA, Buenconsejo J, Quagliarello VJ. Complicated left-sided native valve endocarditis in adults: risk classification for mortality. *JAMA*. 2003;289:1933-40.
- Vikram HR, Buenconsejo J, Hasbun R, Quagliarello VJ. Impact of valve surgery on 6-month mortality in adults with complicated, left-sided native valve endocarditis: a propensity analysis. *JAMA*. 2003;290:3207-14.
- Aksoy O, Sexton DJ, Wang A, Pappas PA, Kourany W, Chu V, et al. Early surgery in patients with infective endocarditis: a propensity score analysis. *Clin Infect Dis*. 2007;44:364-72.
- Croft CH, Woodward W, Elliott A, Commerford PJ, Barnard CN, Beck W. Analysis of surgical versus medical therapy in active complicated native valve infective endocarditis. *Am J Cardiol*. 1983;51:1650-5.
- Richardson JV, Karp RB, Kirklin JW, Dismukes WE. Treatment of infective endocarditis: a 10-year comparative analysis. *Circulation*. 1978;58:589-97.
- Fernicola DJ, Roberts WC. Frequency of ring abscess and cuspal infection in active infective endocarditis involving bioprosthetic valves. *Am J Cardiol*. 1993;72:314-23.
- Thuny F, Beurtheret S, Mancini J, Gariboldi V, Casalta JP, Riberi A, et al. The timing of surgery influences mortality and morbidity in adults with severe complicated infective endocarditis: a propensity analysis. *Eur Heart J*. 2011;32:2027-33.
- Prendergast BD, Tornos P. Surgery for infective endocarditis: who and when? *Circulation*. 2010;121:1141-52.
- Di Salvo G, Habib G, Pergola V, Avierinos JF, Philip E, Casalta JP, et al. Echocardiography predicts embolic events in infective endocarditis. *J Am Coll Cardiol*. 2001;37:1069-76.
- Anguera I, del Rio A, Moreno A, Pare C, Mestres CA, Miro JM. Complications of native and prosthetic valve infective endocarditis: update in 2006. *Curr Infect Dis Rep*. 2006;8:280-8.
- Steckelberg JM, Murphy JG, Ballard D, Bailey K, Tajik AJ, Taliencio CP, et al. Emboli in infective endocarditis: the prognostic value of echocardiography. *Ann Intern Med*. 1991;114:635-40.
- Vilacosta I, Graupner C, San Roman JA, Sarria C, Ronderos R, Fernandez C, et al. Risk of embolization after institution of antibiotic therapy for infective endocarditis. *J Am Coll Cardiol*. 2002;39:1489-95.
- Heiro M, Nikoskelainen J, Engblom E, Kotilainen E, Marttila R, Kotilainen P. Neurologic manifestations of infective endocarditis: a 17-year experience in a teaching hospital in Finland. *Arch Intern Med*. 2000;160:2781-7.
- Conlon PJ, Jefferies F, Krigman HR, Corey GR, Sexton DJ, Abramson MA. Predictors of prognosis and risk of acute renal failure in bacterial endocarditis. *Clin Nephrol*. 1998;49:96-101.
- Pelletier LL Jr, Petersdorf RG. Infective endocarditis: a review of 125 cases from the University of Washington Hospitals, 1963-72. *Medicine (Baltimore)*. 1977;56:287-313.
- Von Reyn CF, Levy BS, Arbeit RD, Friedland G, Crumpacker CS. Infective endocarditis: an analysis based on strict case definitions. *Ann Intern Med*. 1981;94(4 pt 1):505-18.
- Lamas CC, Eykyn SJ. Suggested modifications to the Duke criteria for the clinical diagnosis of native valve and prosthetic valve endocarditis: analysis of 118 pathologically proven cases. *Clin Infect Dis*. 1997;25:713-9.
- Li JS, Sexton DJ, Mick N, Nettles R, Fowler VG Jr, Ryan T, et al. Proposed modifications to the Duke criteria for the diagnosis of infective endocarditis. *Clin Infect Dis*. 2000;30:633-8.
- Murdock DR, Corey GR, Hoen B, Miro JM, Fowler VG Jr, Bayer AS, et al. Clinical presentation, etiology, and outcome of infective endocarditis in the 21st century: the International Collaboration on Endocarditis-Prospective Cohort Study. *Arch Intern Med*. 2009;169:463-73.
- Houpikian P, Raoult D. Blood culture-negative endocarditis in a reference center: etiologic diagnosis of 348 cases. *Medicine (Baltimore)*. 2005;84:162-73.
- Shively BK, Gurule FT, Roldan CA, Leggett JH, Schiller NB. Diagnostic value of transesophageal compared with transthoracic echocardiography in infective endocarditis. *J Am Coll Cardiol*. 1991;18:391-7.
- Erbil R, Rohmann S, Drexler M, Mohr-Kahaly S, Gerharz CD, Iversen S, et al. Improved diagnostic value of echocardiography in patients with infective endocarditis by transoesophageal approach. A prospective study. *Eur Heart J*. 1988;9:43-53.
- Hill EE, Herijgers P, Claus P, Vanderschueren S, Peetermans WE, Herregods MC. Abscess in infective endocarditis: the value of transesophageal echocardiography and outcome: a 5-year study. *Am Heart J*. 2007;154:923-8.
- Habib G. Management of infective endocarditis. *Heart*. 2006;92:124-30.
- Bonow RO, Carabello BA, Chatterjee K, de Leon AC Jr, Faxon DP, Freed MD, et al. 2008 Focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease): endorsed by the Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and

- Interventions, and Society of Thoracic Surgeons. *Circulation*. 2008;118:e523-661.
29. Lee A, Mirrett S, Reller LB, Weinstein MP. Detection of bloodstream infections in adults: how many blood cultures are needed? *J Clin Microbiol*. 2007;11:3546-8.
 30. Baddour LM, Wilson WR, Bayer AS, Fowler VG Jr, Bolger AF, Levison ME, et al. Infective endocarditis: diagnosis, antimicrobial therapy, and management of complications: a statement for healthcare professionals from the Committee on Rheumatic Fever, Endocarditis, and Kawasaki Disease, Council on Cardiovascular Disease in the Young, and the Councils on Clinical Cardiology, Stroke, and Cardiovascular Surgery and Anesthesia, American Heart Association: endorsed by the Infectious Diseases Society of America. *Circulation*. 2005;111:e394-434.
 31. Cosgrove SE, Vigliani GA, Fowler VG Jr, Abrutyn E, Corey GR, Levine DP, et al. Initial low-dose gentamicin for *Staphylococcus aureus* bacteremia and endocarditis is nephrotoxic. *Clin Infect Dis*. 2009;48:713-21.
 32. Fowler VG Jr, Boucher HW, Corey GR, Abrutyn E, Karchmer AW, Rupp ME, et al. Daptomycin versus standard therapy for bacteremia and endocarditis caused by *Staphylococcus aureus*. *N Engl J Med*. 2006;355:653-65.
 33. Bonow RO, Carabello BA, Kanu C, de Leon AC Jr, Faxon DP, Freed MD, et al. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease): developed in collaboration with the Society of Cardiovascular Anesthesiologists: endorsed by the Society for Cardiovascular Angiography and Interventions and the Society of Thoracic Surgeons. *Circulation*. 2006;114:e84-231.
 34. Huang JH, Hsu RB. Treatment of infective endocarditis caused by methicillin-resistant *Staphylococcus aureus*: teicoplanin versus vancomycin in a retrospective study. *Scand J Infect Dis*. 2008;40:462-7.
 35. Vlessis AA, Hovaguimian H, Jaggers J, Ahmad A, Starr A. Infective endocarditis: ten-year review of medical and surgical therapy. *Ann Thorac Surg*. 1996;61:1217-22.
 36. Kang DH, Kim YJ, Kim SH, Sun BJ, Kim DH, Yun SC, et al. Early surgery versus conventional treatment for infective endocarditis. *N Engl J Med*. 2012;366:2466-73.
 37. Thuny F, Avierinos JF, Tribouilloy C, Giorgi R, Casalta JP, Milandre L, et al. Impact of cerebrovascular complications on mortality and neurologic outcome during infective endocarditis: a prospective multicentre study. *Eur Heart J*. 2007;28:1155-61.
 38. Moon MR, Stinson EB, Miller DC. Surgical treatment of endocarditis. *Prog Cardiovasc Dis*. 1997;40:239-64.
 39. Simsir SA, Cheeseman SH, Lancey RA, Vander Salm TJ, Gammie JS. Staged laparoscopic splenectomy and valve replacement in splenic abscess and infective endocarditis. *Ann Thorac Surg*. 2003;75:1635-7.
 40. Basu S, Chrysikos T, Moghadam-Kia S, Zhuang H, Torigian DA, Alavi A. Positron emission tomography as a diagnostic tool in infection: present role and future possibilities. *Semin Nucl Med*. 2009;39:36-51.
 41. Vind SH, Hess S. Possible role of PET/CT in infective endocarditis. *J Nucl Cardiol*. 2010;17:516-9.
 42. Van Riet J, Hill EE, Gheysens O, Dymarkowski S, Herregods MC, Herijgers P, et al. (18)F-FDG PET/CT for early detection of embolism and metastatic infection in patients with infective endocarditis. *Eur J Nucl Med Mol Imaging*. 2010;37:1189-97.
 43. Glazier JJ, Verwilghen J, Donaldson RM, Ross DN. Treatment of complicated prosthetic aortic-valve endocarditis with annular abscess formation by homograft aortic root replacement. *J Am Coll Cardiol*. 1991;17:1177-82.
 44. Walkes JCM, Reardon MJ. Current thinking in stentless valve surgery. *Curr Opin Cardiol*. 2003;18:117-23.
 45. Farhat F, Durand M, Delahaye F, Jegaden O. Prosthetic valve sewing-ring sealing with antibiotic and fibrin glue in infective endocarditis. A prospective clinical study. *Interact Cardiovasc Thorac Surg*. 2007;6:16-20.
 46. Watanabe G, Haverich A, Speier R, Dresler C, Borst HG. Surgical treatment of active infective endocarditis with paravalvular involvement. *J Thorac Cardiovasc Surg*. 1994;107:171-7.
 47. Karck M, Siclari F, Wahlig H, Sperling U, Schmid C, Haverich A. Pretreatment of prosthetic valve sewing-ring with the antibiotic/fibrin sealant compound as a prophylactic tool against prosthetic valve endocarditis. *Eur J Cardiothorac Surg*. 1990;4:142-6.
 48. Muehrcke DD, Cosgrove DM III, Lytle BW, Taylor PC, Burgar AM, Durnwald CP, et al. Is there an advantage to repairing infected mitral valves? *Ann Thorac Surg*. 1997;63:1718-24.
 49. Lee EM, Shapiro LM, Wells FC. Conservative operation for infective endocarditis of the mitral valve. *Ann Thorac Surg*. 1998;65:1087-92.
 50. Jung B, Rousseau-Pazaud J, Cormier B, Garbarz E, Fondard O, Brochet E, et al. Contemporary results of mitral valve repair for infective endocarditis. *J Am Coll Cardiol*. 2004;43:386-92.
 51. de Kerchove L, Price J, Tamer S, Glineur D, Momeni M, Noirhomme P, et al. Extending the scope of mitral valve repair in active endocarditis. *J Thorac Cardiovasc Surg*. 2012;143(Suppl):S91-5.
 52. De La Zerda DJ, Cohen O, Marelli D, Esmailian F, Hekmat D, Laks H. Long-term results of mitral valve repair using autologous pericardium annuloplasty. *J Heart Valve Dis*. 2008;17:10-5.
 53. Zegdi R, Debieche M, Latremouille C, Lebied D, Chardigny C, Grinda JM, et al. Long-term results of mitral valve repair in active endocarditis. *Circulation*. 2005;111:2532-6.
 54. Sternik L, Zehr KJ, Orszulak TA, Mullany CJ, Daly RC, Schaff HV. The advantage of repair of mitral valve in acute endocarditis. *J Heart Valve Dis*. 2002;11:91-7; discussion 7-8.
 55. Ruttman E, Legit C, Poelzl G, Mueller S, Chevtchik O, Cottogni M, et al. Mitral valve repair provides improved outcome over replacement in active infective endocarditis. *J Thorac Cardiovasc Surg*. 2005;130:765-71.
 56. Kumar AS, Choudhary SK, Mathur A, Saxena A, Roy R, Chopra P. Homograft mitral valve replacement: five years' results. *J Thorac Cardiovasc Surg*. 2000;120:450-8.
 57. Chauvaud S, Waldmann T, d'Attellis N, Bruneval P, Acar C, Gerota J, et al. Homograft replacement of the mitral valve in young recipients: mid-term results. *Eur J Cardiothorac Surg*. 2003;23:560-6.
 58. Yankah AC, Pasic M, Klose H, Siniawski H, Weng Y, Hetzer R. Homograft reconstruction of the aortic root for endocarditis with periannular abscess: a 17-year study. *Eur J Cardiothorac Surg*. 2005;28:69-75.
 59. Yankah AC, Klose H, Petzina R, Musci M, Siniawski H, Hetzer R. Surgical management of acute aortic root endocarditis with viable homograft: 13-year experience. *Eur J Cardiothorac Surg*. 2002;21:260-7.
 60. Obadia JF, Raisky O, Sebbag L, Chocron S, Saroul C, Chassignolle JF. Monobloc aorto-mitral homograft as a treatment of complex cases of endocarditis. *J Thorac Cardiovasc Surg*. 2001;121:584-6.
 61. Ferguson E, Reardon MJ, Letsou GV. The surgical management of bacterial valvular endocarditis. *Curr Opin Cardiol*. 2000;15:82-5.