Surgical treatment of right-sided infective endocarditis

James C. Witten, BA,[a] Syed T. Hussain, MD,[b] Nabin K. Shrestha, MD,[c] Steven M. Gordon, MD,[c] Penny L. Houghtaling, MS,[d] Faisal G. Bakaeen, MD,[b] Brian Griffin, MD,[e] Eugene H. Blackstone, MD,[b,d] and Gösta B. Pettersson, MD, PhD[b]

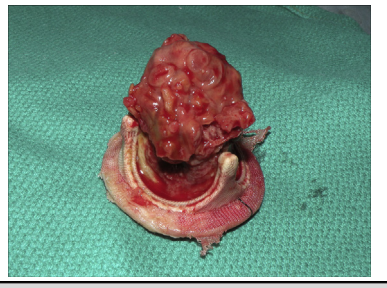
ABSTRACT

Objective: Right-sided infective endocarditis is increasing because of increasing prevalence of predisposing conditions, and the role and outcomes of surgery are unclear. We therefore investigated the surgical outcomes for right-sided infective endocarditis.

Methods: From January 2002 to January 2015, 134 adults underwent surgery for right-sided infective endocarditis. Patients were grouped according to predisposing condition. Hospital outcomes, time-related death, and reoperation for infective endocarditis were analyzed.

Results: A total of 127 patients (95%) had tricuspid valve and 7 patients (5%) pulmonary valve infective endocarditis; 66 patients (49%) had isolated right-sided infective endocarditis, and 68 patients (51%) had right- and left-sided infective endocarditis. Predisposing conditions included injection drug use (30%), cardiac implantable devices (26%), chronic vascular access (19%), and other/none (25%). One native tricuspid valve was excised, 76% were repaired or reconstructed, and 23% were replaced. Intensive care unit and postoperative hospital stays were similar among groups. Injection drug users had the best early survival (no hospital mortality), and patients with chronic vascular access had the worst late survival (18% at 5 years). Survival was worst for concomitant mitral valve versus isolated right-sided infective endocarditis or concomitant aortic valve infective endocarditis. Survival after tricuspid valve replacement was worse than after repair/reconstruction. Estimated glomerular filtration rate was the strongest risk factor for death, not predisposing condition. Eleven patients underwent 12 reoperations for infective endocarditis; more reoperations occurred in injection drug users ($P = .03$).

Conclusions: Overall outcomes after surgery are variable and affected by patient condition, not predisposing condition. Injection drug use carries a higher risk of reoperation for infective endocarditis. Earlier surgery may permit more valve repairs and improve outcomes. Whenever possible, tricuspid valve replacement should be avoided. (J Thorac Cardiovasc Surg 2019;157:1418-27)



Large prosthetic tricuspid valve vegetation causing overwhelming septic pulmonary emboli.

Central Message

Increasing prevalence of right-sided endocarditis is concerning, and the role and timing of surgery remain unclear. Surgical outcomes are more affected by comorbidities than predisposing conditions.

Perspective

Right-sided IE is increasing secondary to the increase in predisposing conditions. The role and outcomes of surgery are unclear. Understanding that comorbidities drive mortality risk and that mortality and prevalence of reoperation are low may justify earlier surgery and lead to more tricuspid valve repairs and better outcomes.

See Commentaries on pages 1428 and 1430.

Infective endocarditis (IE) carries high morbidity and mortality and most frequently affects the left side of the heart; in contrast, right-sided IE, which accounts for 5% to 10% of cases, is thought to be more benign, with most cases managed medically. It mainly affects the tricuspid valve,[1-4] with valve replacement

From the [a]Education Institute, Cleveland Clinic Lerner College of Medicine, Cleveland, Ohio; [b]Heart and Vascular Institute, Department of Thoracic and Cardiovascular Surgery; [c]Medicine Institute, Department of Infectious Disease; [d]Research Institute, Department of Quantitative Health Sciences; and [e]Medicine Institute, Department of Cardiovascular Medicine, Cleveland Clinic, Cleveland, Ohio.

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Address for reprints: Gösta B. Pettersson, MD, PhD, Department of Thoracic and Cardiovascular Surgery, Cleveland Clinic, 9500 Euclid Ave/Desk J4-1, Cleveland, OH 44195 (E-mail: petterg@ccf.org).

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Abbreviation and Acronym
IE = infective endocarditis

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performed in most surgical cases[5]; pulmonary valve involvement is rare.[2,3,6]

Injection drug use is the leading cause of right-sided IE in the western world, and its prevalence is increasing in the current opioid epidemic.[7] However, prevalence of other predisposing conditions is also on the rise, as more cardiac devices are implanted in the right heart, including pacemakers, implantable cardioverter-defibrillators, and resynchronization devices, and because use of central catheters, arteriovenous fistulas for renal dialysis, and repaired congenital heart disease is increasing.[3] Even the spectrum of causative organisms is changing.[3,4,8] The specific predisposing condition is sometimes used to advocate for or against surgery.[9,10]

Most previous studies of right-sided IE have focused on injection drug use, with only a few discussing the changing profile of the disease and contemporary results of surgical treatment.[1,7,9,11] There is also a paucity of data on isolated right-sided IE versus combined right- and left-sided IE, which may affect outcomes.[1] We therefore (1) reviewed predisposing condition, patient characteristics, microbiology, and cardiac pathology; (2) identified risk factors for poor outcomes; and (3) assessed IE recurrence in patients who underwent surgery for right-sided IE over the past decade at Cleveland Clinic.

PATIENTS AND METHODS

Patients

From January 1, 2002, to January 1, 2015, 1292 consecutive adults underwent surgery for IE at Cleveland Clinic, of whom 134 (10%) had right-sided IE. All met modified Duke criteria for definite IE.[12]

Data Sources and Abstraction

IE surgical pathology was coded as previously described using medical records, operative reports, and echocardiography reports.[13] The Cardiovascular Information Registry was queried for patient characteristics, operative details, and postoperative course. Data used for the study were approved for use in research by the Cleveland Clinic Institutional Review Board, with patient consent waived.

Predisposing Condition

Patients were categorized into 1 of 4 predisposing condition groups: injection drug use, cardiac implantable device, chronic vascular access, and other/none. Patients with cardiac implantable devices were considered to have right-sided IE when the tricuspid valve was convincingly infected.

The other/none group (n = 33) comprised 3 subgroups: (1) congenital heart anomalies (10/33, 30%), (2) invasive fistula tracts from left-sided IE (8/33, 24%), and (3) IE without clear predisposing conditions (15/33, 46%) (Table E1). Presence of prosthetic valves was found in all groups (Table 1).

Indications for Surgery

Factors persuasive for surgery (indications) were identified by review of hospital records and operative reports. They included severe valvular regurgitation from valve damage or destruction or prosthetic valve dehiscence; right heart failure with peripheral edema, hepatic congestion, right ventricular systolic dysfunction, and right ventricular dilatation; left heart failure with pulmonary congestion, reduced ejection fraction, left ventricular dilatation, and low cardiac index; septic emboli; large vegetations greater than 15 mm in 1 direction on echocardiogram; failure of medical therapy with sepsis lasting more than 5 to 7 days; fistulas, abscesses, or pseudoaneurysm formation; and a conduction defect such as worsening degree of heart block. In patients with both right- and left-sided IE, the left-sided disease often provided the main indications for surgery.

Microorganisms

Causative organisms were retrieved from microbiologic laboratory reports and validated by infectious disease specialists. Information on causative organism included universal bacterial polymerase chain reaction results.

Infective Endocarditis Management and Surgery

IE management was by a multidisciplinary team comprising infectious disease physicians, cardiologists, cardiothoracic surgeons, and other specialists. This team-based approach was ongoing throughout the study period and reflects a culture existing ahead of guidelines[14,15]; it was folded into the 2017 American Association for Thoracic Surgery guidelines for surgical treatment of IE.[16]

Once the patient has an indication for operation, surgery is expedited. Our surgical approach is debridement of all infected tissues and foreign material, followed by generous irrigation. Local antiseptics and antibiotics are used sparingly. Tricuspid valve repair or reconstruction is performed whenever possible using a variety of reconstruction techniques, including use of autologous pericardium and artificial chords for leaflet reconstruction (Video 1) with or without suture or ring anuloplasty. Rather than replacing the valve with a prosthetic device, important residual TR was frequently accepted. When replacement is deemed unavoidable, we use a bioprosthesis. Valvectomy without replacement was used once in this series.

End Points

End points were all-cause mortality after surgery and recurrent IE. Follow-up data were obtained through medical record review of subsequent examinations at Cleveland Clinic, mailed Institutional Review Board–approved questionnaires, and telephone contact. All patients were followed for vital and recurrence status within 6 months of the cross-sectional closing date (Figure E1). Median follow-up of survivors was 5.2 years, with 25% of survivors followed more than 8 years and 10% more than 10 years.

Patients with recurrent IE met the modified Duke criteria for IE subsequent to discharge after the index hospitalization. Recurrence was categorized as IE "relapse" or "reinfection" based on timing and microbiology. If microbiology was consistent between episodes and recurrence occurred within 6 months after index surgery, it was considered disease relapse; if microbiology was disparate between episodes, or recurrence occurred more than 6 months after index operation, it was classified as reinfection. Other outcomes included in-hospital postoperative complications, defined according to The Society of Thoracic Surgeons Adult Cardiac Surgery database.[17]

TABLE 1. Baseline characteristics of patients undergoing surgery for right-sided infective endocarditis according to predisposing condition

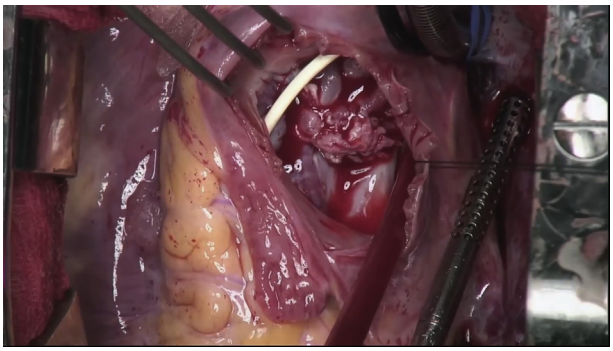
Characteristics	Predisposing condition				*P*
	Injection drug use (n = 40) No. (%) or median [15th, 85th percentiles]	Cardiac implantable device (n = 35) No. (%) or median [15th, 85th percentiles]	Chronic vascular access (n = 26) No. (%) or median [15th, 85th percentiles]	Other/none (n = 33) No. (%) or median [15th, 85th percentiles]	
Demographics					
Age (y)	34 [26, 49]	62 [43, 77]	50 [37, 62]	55 [30, 69]	<.0001
Female	22 (55)	11 (31)	10 (38)	14 (42)	.2
Body mass index (kg/m^2)	22 [20, 28]	27 [22, 39]	27 [22, 36]	26 [21, 31]	.0009
Presentation					
NYHA functional class III-IV	11/33 (33)	11/33 (33)	11/24 (46)	13/31 (42)	.3
Emergency operation	4 (10)	1 (2.9)	0 (0)	2 (6.1)	.3
Prior stroke	6 (15)	6 (17)	7 (27)	4 (12)	.5
Prior myocardial infarction	3 (7.5)	13 (37)	5 (19)	5 (15)	.01
Acute or chronic renal disease requiring dialysis	1 (2.5)	2 (5.7)	14 (54)	1 (3.0)	<.0001
Preoperative eGFR (mL/min/1.73 m^2)	80 [44, 144]	68 [37, 99]	16 [10, 98]	75 [35, 108]	<.0001
Iatrogenic source of infection	4 (10)	2 (5.7)	0 (0)	8 (24)	.01
Cardiac comorbidity					
Prior IE	8 (20)	2 (5.7)	2 (7.7)	3 (9.1)	.2
Prior complete heart block or pacer	3 (7.5)	14/34 (41)	3/24 (13)	3/32 (9.4)	.0005
Prior cardiac operations					.5
0	29 (73)	17 (49)	16 (62)	18 (55)	
1	8 (20)	11 (31)	7 (27)	11 (33)	
2	3 (7.5)	6 (17)	3 (12)	2 (6.1)	
3+	0 (0)	1 (2.9)	0 (0)	2 (6.1)	
Valve affected					
Aortic	7 (18)	8 (23)	10 (38)	20 (61)	.0006
Mitral	12 (30)	7 (20)	11 (42)	11 (33)	.3
Tricuspid	39 (98)	35 (100)	26 (100)	27 (82)	.002
Pulmonary	1 (2.5)	0 (0)	0 (0)	6 (18)	.002
Right-sided IE only	23 (58)	23 (66)	10 (38)	11 (33)	.02
Prosthetic valve endocarditis					
Any valve	11 (28)	7 (20)	6 (23)	11 (33)	.6
Aortic valve	4 (10)	6 (17)	3 (12)	6 (18)	.7
Mitral valve	1 (2.5)	2 (5.7)	3 (12)	2 (6.1)	.5
Tricuspid valve	8 (20)	0 (0)	0 (0)	2 (6.1)	.003
Pulmonary valve	1 (2.5)	0 (0)	0 (0)	3 (9.1)	.10
Infectious fistula from left to right	2 (5.0)	2 (5.7)	4 (15)	8 (24)	.02
Noncardiac comorbidity					
Peripheral arterial disease	3 (7.5)	7 (20)	9 (35)	3 (9.1)	.02
Immunosuppression	0 (0)	1 (2.9)	6 (23)	1 (3.0)	.0006
Hypertension	18 (45)	21 (60)	22 (85)	18 (55)	.01
Pharmacologically treated diabetes	2 (5.0)	10/34 (29)	11 (42)	8/32 (25)	.004

NYHA, New York Heart Association; *eGFR*, estimated glomerular filtration rate; *IE*, infective endocarditis.

Data Analysis

All analyses were performed using SAS statistical software (version 9.4; SAS Institute, Inc, Cary, NC). Continuous variables are summarized as mean ± standard deviation or as equivalent 15th/50th/85th percentiles when values were skewed; comparisons were made using the Wilcoxon rank-sum test. Categoric variables are summarized as frequencies and percentages; comparisons were made using the chi-squared test or Fisher's exact test when frequency was less than 5. Uncertainty is expressed by confidence limits equivalent to ±1 standard error (68%).

Time-related all-cause mortality and IE recurrence were estimated nonparametrically using the Kaplan–Meier method and the Andersen method for competing risks,[18] and parametrically using a multiphase nonproportional hazards model.[19] Multivariable analysis was performed in the hazard function domain, in which variables modulating each hazard phase were considered simultaneously. Variable selection from among those listed in Appendix E1, with a *P*-value criterion for retention of .05 or less, used a machine-learning bootstrap-aggregation method involving unsupervised variable selection based on 1000 bootstrap samples.[20,21] Frequency of occurrence of single and closely related clusters of factors selected in these analyses was tabulated and indicated reliability of each variable. Variables with bootstrap reliability of 50% or greater were retained in the final model. Thereafter, predisposing conditions were forced into the



VIDEO 1. Debridement and reconstruction of the tricuspid valve. Reconstruction is performed using untreated autologous pericardium and artificial chords. Video available at: https://www.jtcvs.org/article/S0022-5223(18)32475-9/fulltext.

final model to assess risk-adjusted estimates, regardless of statistical significance.

RESULTS

Right-Sided Infective Endocarditis

Of the 134 patients, 127 (95%) had tricuspid valve and 7 (5%) pulmonary valve IE. Sixty-seven patients (50%) had isolated right-sided IE, and 67 (50%) had right- and left-sided IE (Figure E2).

Infective Endocarditis According to Predisposing Condition

The predisposing condition was injection drug use in 40 patients (30%), cardiac implantable device in 35 patients (26%), chronic vascular access in 26 patients (19%), and other/none in 33 patients (25%). Injection drug users were the youngest group. Those with cardiac implantable devices often had complete heart block (41% of group). Those with chronic vascular access had more comorbidities, and 54% were on dialysis.

New York Heart Association functional class, emergency status at operation, and history of stroke were similar across predisposing conditions, as was history of IE, prior cardiac surgery, and prosthetic valve IE of any valve (Table 1). Prosthetic valves were frequent across groups (20%-33%), with prosthetic tricuspid valve IE most common in injection drug users (20%). Injection drug users and patients with cardiac implantable devices were more likely to have isolated right-sided IE, whereas those with chronic vascular access and those in the other/none group were more likely to have right- and left-sided IE. The pulmonary valve was particularly affected in the other/none group (18%), including 3 native pulmonary valve infections, 2 pulmonary allograft infections, and 1 bioprosthetic valved-conduit infection (Table E2).

Mitral valve involvement was similar across predisposing conditions; however, concomitant aortic valve IE was most common in the other/none group (61%). Right-sided infection occurred through invasive fistula tracts from the left side in 15 (22%).

Indications for Surgery

Severe valve regurgitation, heart failure, and septic emboli were the most common clinical sequelae persuasive for surgery (Table 2). Large vegetations and medical failure were also often indications for surgery. A combination of large vegetations and septic pulmonary emboli were most commonly cited in injection drug users. For patients with cardiac implantable devices, large vegetations were the most common indications. Large vegetations were least common in the other/none group.

Microorganisms

The most common genus was staphylococcus, with *Staphylococcus aureus* (38%) and coagulase-negative staphylococci (23%) together infecting 61% of the cohort (Table 2). Microbiology varied by predisposing condition: Injection drug users were predominantly infected by *S aureus*, whereas the other/none group had many atypical organisms. Nearly half (22/54, 41%) of *S aureus* infections in the cohort were caused by methicillin-resistant organisms. All enterococcus isolates were vancomycin-susceptible. Four patients had fungal IE (Table E3).

Infective Endocarditis Surgery

Surgery consisted of debridement and repair/reconstruction or replacement of damaged valves (Table 3). In patients with native tricuspid valve involvement, 90 (76%) had valve repair/reconstruction and 27 (23%) had prosthetic valve replacement. One patient had a subtotal valvectomy without replacement. In addition to leaflet reconstructions and artificial chords, an anuloplasty ring was used in 27 patients (30%) and suture anuloplasty in the remaining tricuspid valve repair/reconstructions. Tricuspid regurgitation at discharge was none or mild in the majority of patients receiving repair/reconstruction; however, 21% left the operating room with moderate and 23% with severe TR (Figure E3). During 5 years of echocardiographic follow-up, less than 10% experienced worsening of their regurgitation.

Replacement was similar across predisposing conditions. Tricuspid valve replacements were with stented bioprostheses except for 1 pulmonary allograft. The pulmonary valve was repaired in 2 patients (30%) and replaced with a pulmonary allograft in 5 patients (70%).

Patients in the other/none group had the shortest overall hospital stay (Table E4). Acute postoperative renal failure occurred in 23% of patients with cardiac implantable devices and 24% of those in the other/none predisposing condition group (Table E4). Prolonged ventilation was common across all groups. Heart block developed in 9 (15%) of those patients with isolated tricuspid valve IE (n = 62) (Table E5). These heart blocks occurred in patients who

TABLE 2. Disease characteristics persuasive of need for surgery (indications)

Characteristics	Predisposing condition				P
	Injection drug use (n = 40) No. (%)	Cardiac implantable device (n = 35) No. (%)	Chronic vascular access (n = 26) No. (%)	Other/none (n = 33) No. (%)	
Persuasive clinical finding*					
Severe valve regurgitation	29 (73)	16 (46)	19 (73)	22 (67)	.06
Right heart failure	12 (30)	8 (23)	7 (27)	8 (24)	.9
Left heart failure	9 (23)	10 (29)	10 (38)	17 (52)	.06
Septic emboli	31 (78)	9 (26)	12 (46)	16 (48)	.0001
Pulmonary	28 (70)	8 (23)	11 (42)	13 (39)	.0005
Systemic	7 (18)	1 (2.9)	3 (12)	5 (15)	.2
Cerebral	9 (23)	1 (2.9)	2 (7.7)	3 (9.1)	.06
Large vegetations	24 (60)	21 (60)	12 (46)	10 (30)	.04
Medical failure/uncontrolled infections	11 (28)	9 (26)	8 (31)	14 (42)	.4
Valve destruction or damage	7 (18)	6 (17)	5 (19)	9 (27)	.7
Prosthetic valve dehiscence	4 (10)	6 (17)	6 (23)	6 (18)	.6
Fistula, abscess, pseudoaneurysm	4 (10)	7 (20)	5 (19)	10 (30)	.19
PFO/ASD/VSD	3 (7.5)	3 (8.6)	1 (3.8)	8 (24)	.02
Worsening heart block/conduction defect	3 (7.5)	2 (5.7)	3 (12)	4 (12)	.8
Microbiology					.0007
Staphylococcus aureus	27 (68)	10 (29)	9 (35)	8 (24)	
Coagulase-negative staphylococcus†	2 (5.0)	15 (43)	8 (31)	8 (24)	
Enterococcus	1 (2.5)	3 (8.6)	1 (3.8)	3 (9.1)	
Viridans group streptococcus	4 (10)	0 (0)	1 (3.8)	2 (6.1)	
Other‡	0 (0)	2 (5.7)	4 (15)	8 (24)	
Polymicrobial§	2 (5.0)	1 (2.9)	1 (3.8)	0 (0)	
Fungus‖	1 (2.5)	2 (5.7)	1 (3.8)	0 (0)	
Pathogen not identified	3 (7.5)	2 (5.7)	1 (3.8)	4 (12)	

PFO/ASD/VSD, Patent foramen ovale/atrial septal defect/ventricular septal defect. *Not mutually exclusive. †Includes 3 cases of *S lugdunensis*, 1 in chronic vascular access and 2 in cardiac implantable device. ‡Includes *Abiotropha defectiva*, *Achromobacter xylosoxidans*, *Bartonella henselae*, *Cardiobacterium hominis*, *Brevibacterium otitidis*, *Enterobacter cloacae*, *Mycobacterium chenolae-abscessus complex*, 2 *Pseudomonas aeruginosa*, *Cutibacterium* (formerly *Propionibacterium*) *acnes*, *Proteus vulgaris*, 2 *Streptococcus pneumoniae*, *Streptococcus pyogenes*. §Includes coagulase-negative staphylococcus and viridans group streptococcus; *Pseudomonas aeruginosa* and viridans group streptococcus; *Candida albicans* and *Pseudomonas aeruginosa*; coagulase-negative staphylococcus and *Pseudomonas aeruginosa*. ‖Includes 1 *Aspergillus fumigatus*, 2 *Candida albicans*, and 1 *Candida tropicalis*.

underwent replacement of the tricuspid valve, aortic valve, or both, except for 1 who underwent tricuspid valve repair and closure of a ventricular septal defect.

Mortality

In-hospital mortality was 5.9%, with no significant differences across predisposing conditions, although no injection drug user died in-hospital ($P = .18$, Table E4). Among 134 patients, 70 deaths occurred by end of follow-up. Risk of death was high during the first 6 months after surgery, followed by a slowly decreasing late hazard, which was similar across predisposing conditions (Figure E4, *A*-*C*).

Survival varied by predisposing condition (*P[log-rank]* = .009; Figure 1). Injection drug users had the highest early survival (92% at 6 months), and patients with chronic vascular access had the lowest early and late survival (73% at 6 months, 18% at 5 years); 5-year survival was 59% in patients with cardiac implantable devices and 69% in the other/none group. Survival in patients with isolated right-sided IE and left- and right-sided IE was similar when stratified by predisposing condition (Figure E5, *A* and *B*). Survival was lower for patients with combined right- and left-sided IE than for those with isolated right-sided IE ($P = .03$; Figure E6). Patients with IE involving the mitral or mitral + aortic valves had worse survival than those with right- and left-sided IE involving the aortic valve or with right-sided IE only ($P = .002$; Figure 2). Patients who underwent tricuspid valve repair/reconstruction had better survival than those undergoing tricuspid replacement (Figures 3 and E7).

On multivariable analysis, poor kidney function, tricuspid valve replacement at index operation, peripheral arterial disease, and mitral valve involvement affected late survival (Table E6), but predisposing condition was not an independent risk factor.

Infective Endocarditis Relapse/Recurrence

Thirteen patients developed recurrent IE 14 times, 5 relapses and 9 reinfections (Table E7). Eleven patients underwent 12 reoperations during follow-up, and 2 were treated

TABLE 3. Operative details

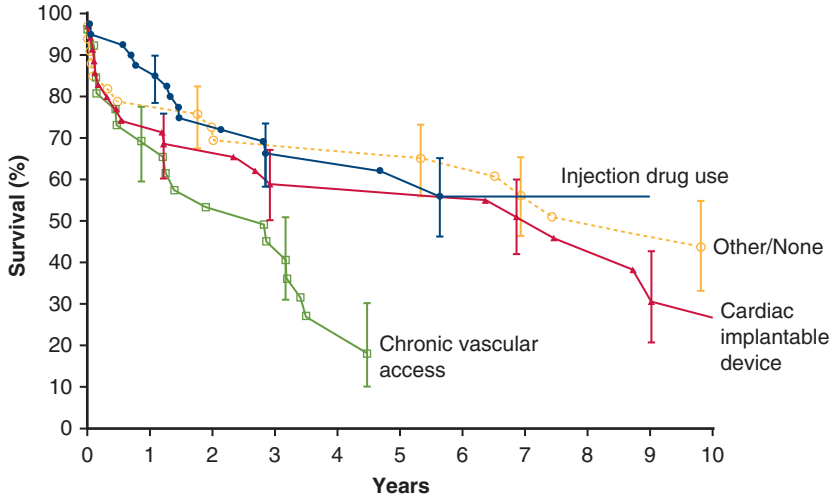
Operation performed	Predisposing condition: Injection drug use (n = 40) No. (%)	Cardiac implantable device (n = 35) No. (%)	Chronic vascular access (n = 26) No. (%)	Other/none (n = 33) No. (%)	*P*
Tricuspid valve					
Repair/reconstruction	26 (65)	26 (74)	18 (69)	23 (70)	.9
With anuloplasty ring	6 (23)	6 (24)	11 (61)	4 (17)	.02
Replacement	14 (35)	9 (26)	8 (31)	6 (18)	.4
Pulmonary valve					
Repair	0 (0)	0 (0)	0 (0)	2 (6.1)	.6
Replacement	1 (3.0)	0 (0)	0 (0)	4 (12)	.6
Aortic valve					
Repair	1 (2.5)	1 (2.9)	1 (3.8)	1 (3.0)	>.9
Replacement	7 (18)	8 (23)	9 (35)	19 (58)	.002
Mitral valve					
Repair	5 (13)	3 (8.6)	9 (35)	8 (24)	.04
With anuloplasty ring	4 (80)	1 (25)	4 (44)	6 (75)	.8
Replacement	8 (20)	4 (11)	4 (15)	6 (18)	.8
Epicardial pacemaker lead placement	15 (38)	21 (60)	6 (23)	11 (33)	.02

medically. Five-year freedom from recurrence was 87% (Figures E8 and E9). Nine of the 13 patients (69%) were injection drug users, with 5-year freedom from recurrence of 76% compared with 93% for other predisposing conditions (Figure 4). Two recurrences were in patients with a history of IE surgery, similar to those without prior IE surgery (Figure E10). IE recurrence did not differ significantly between those who underwent tricuspid repair/reconstruction versus replacement.

DISCUSSION

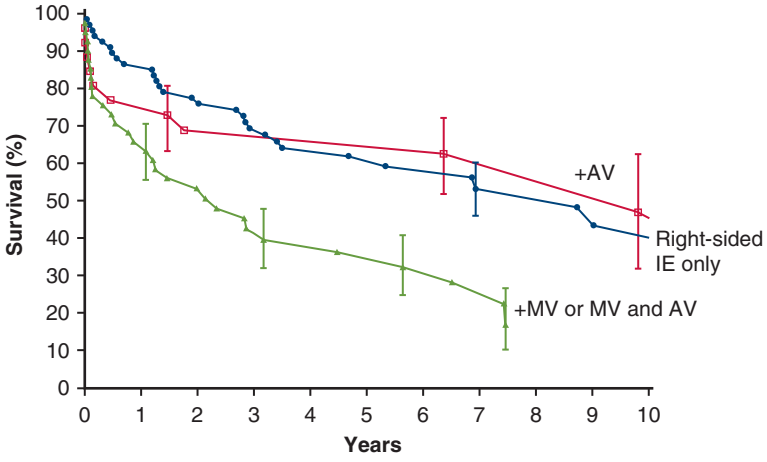
Principal Findings

Patient characteristics differed across predisposing conditions. Surgical management focused on thorough



# at risk						
Drug use	40	28	20	10	6	4
CID	35	24	19	16	9	5
Vasc. access	26	14	4	2	-	-
Other/none	33	24	20	16	10	5

FIGURE 1. Survival after surgery for right-sided IE stratified by predisposing condition. Each *symbol* represents a death and *vertical bars* 68% confidence limits equivalent to ±1 standard error. Number of patients at risk is shown periodically beneath the horizontal axis. The injection drug use group is denoted by *blue line* and *filled circles*, cardiac implantable device (*CID*) group is denoted by *red line* and *triangles*, chronic vascular access group is denoted by *green line* and *squares*, and other/none group is denoted by *yellow dashed line* and *open circles*.



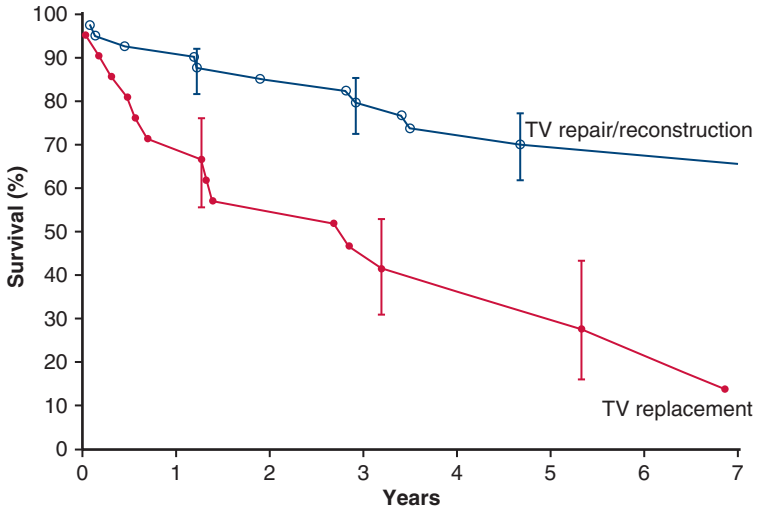
# at risk						
RSIE only	67	51	33	22	13	10
+AV	26	17	15	12	9	3
+MV or MV+AV	41	21	14	9	3	1

FIGURE 2. Survival after surgery for right-sided IE stratified by valves affected. Format is as in Figure 1. Right-sided IE (*RSIE*)-only group is denoted by *blue line* and *filled circles*, right-sided IE + concomitant aortic valve (*AV*) IE group is denoted by *red line* and *squares*, and right-sided IE + concomitant mitral valve (*MV*) or MV + AV involvement is denoted by *green line* and *triangles*. *IE*, Infective endocarditis.

debridement and valve repair/reconstruction when possible, which was achieved in a high proportion of patients. Early and late mortality varied by predisposing condition; however, only poor kidney function, tricuspid valve replacement, peripheral arterial disease, and mitral valve involvement were risk factors. Relapse or recurrence of IE was uncommon except in injection drug users.

Infective Endocarditis Predisposing Conditions

IE involving right-sided valves has become an increasing problem with the steady increase in predisposing conditions, including doubling of injection heroin use in the last decade[22] and accelerated use of cardiac implantable devices.[23] The makeup of predisposing condition groups in our study followed these reported trends, including younger



# at risk								
Repair/reconstruction	41	39	34	30	23	19	17	15
Replace	21	16	18	10	7	5	3	2

FIGURE 3. Survival after tricuspid repair/reconstruction or tricuspid replacement for tricuspid IE only. Format is as in Figure 1. *TV*, Tricuspid valve.

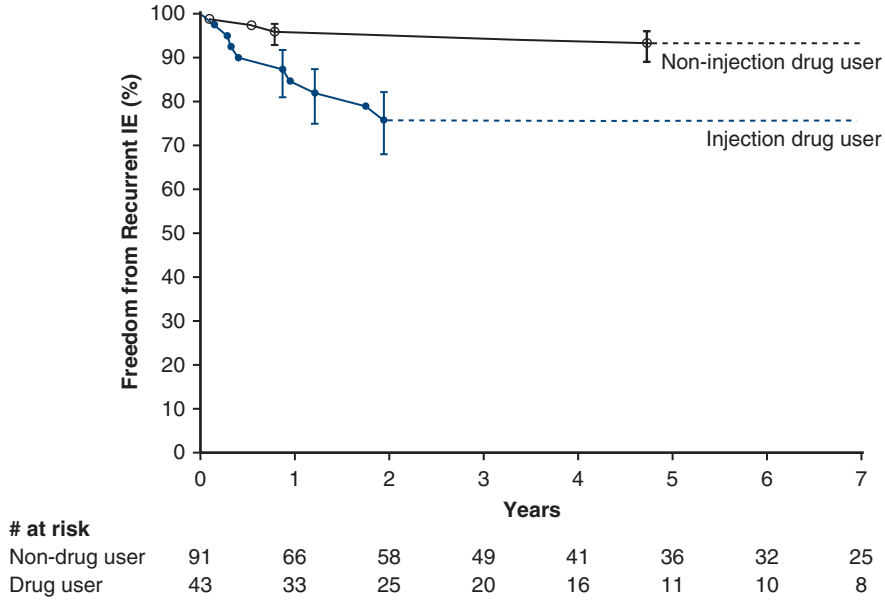


FIGURE 4. Freedom from relapse/recurrent IE after surgery for right-sided IE, stratified by injection drug use or not. Format is as in Figure 1. Injection drug use group is denoted by *blue line* and *filled circles*, and combined other groups are represented by *black dashed line* and *open circles*. *IE*, Infective endocarditis.

age for injection drug users and more comorbidities for patients with chronic vascular access.[9,10]

Manifestations of IE varied among predisposing conditions: Injection drug users were nearly as likely to have combined right- and left-sided IE as isolated right-sided IE. Those with chronic vascular access were more likely to have combined right- and left-sided IE. Conversely, those with a cardiac implantable device were almost twice as likely to have isolated right-sided IE.

The other/none group was heterogeneous. In some, congenital septal anomalies provided a pathway to seeding right-sided valves from left-sided IE. Another source in this group was invasion of left-sided IE through a fistula tract, usually from an infected aortic valve and root. Many also had a prosthetic aortic valve, the presence of which increases risk of invasive IE.[24] This group also contained patients for whom no predisposing factor was identified, a trait more commonly found in isolated left-sided IE.[25]

Indications for Surgery

Surgical indications and intervention algorithms for left-sided IE are well established, but this is not true for right-sided IE.[16] For right-sided IE, we operate for large vegetations to eliminate the source of infection, prevent further showering of lungs with septic emboli, and eliminate severe tricuspid valve regurgitation. Because moderate tricuspid regurgitation is well tolerated, optimal timing of intervention is difficult to estimate. When an operation is performed early in the course of disease, surgical risk is low.

With increasing septic pulmonary embolism burden, risk increases and the window of opportunity to intervene may close as pulmonary complications lead to a rapid decline in patient status. The lungs themselves can become a primary source of infection, causing persistent bacteremia.[26] Most injection drug users in our series had septic pulmonary emboli, either alone or along with systemic emboli. In an otherwise healthy young patient, these often were persuasive for surgery. Injection drug use itself is also a direct source of pulmonary sepsis.

Causative Organisms

In injection drug users, *S aureus* is the dominant organism (68% in our series and 60%-90% in others).[4] In our series, *S aureus* was not a significant risk factor for death, which may be explained by more timely operations for these infections than for other pathogens and by the noninvasiveness of right-sided infections.[24]

Infective Endocarditis Treatment

Right-sided IE is typically treated conservatively.[1,11,27] When indicated, however, surgical treatment of right-sided IE can be performed with good early, mid-term, and long-term results.[1,4,5,28,29]

Our experience supports making every effort to avoid replacing the tricuspid valve, with valve replacement performed only if repair is impossible.[1,28,29] Valve repair may include reconstruction procedures such as replacement of large portions of the leaflets with autologous pericardium or other patch material and support with artificial chordae. Many of our repair patients left the operating room and hospital with moderate or severe tricuspid regurgitation. We have come

to accept this rather than replacing the valve, which is associated with worse survival. Residual tricuspid regurgitation appeared to be stable over time.

Valvectomy without replacement, performed for 1 of our patients, requires normal lungs with low pulmonary vascular resistance and is advocated only in extreme cases (such as in patients with high risk of injection drug use relapse). These patients usually require subsequent valve replacement once the infection is cured.[30] We do not believe that valvectomy or severe tricuspid regurgitation will be tolerated in patients with elevated pulmonary vascular resistance.

Survival in the setting of combined right-sided IE and invasive aortic + mitral IE is poor,[25] with reconstruction of the intervalvular fibrosa required. Techniques include the ''commando'' or ''hemi-commando'' procedure.[31]

Mortality After Infective Endocarditis Surgery

Reported surgical mortality for isolated right-sided IE in North America is 6%,[5] commensurate with our in-hospital mortality across the cohort, although outcomes are more favorable for isolated right-sided IE than right- and left-sided IE.[1,32] Mitral valve involvement was associated with higher mortality, whereas aortic valve involvement was not, both findings consistent with our previous studies.[25]

Patients with chronic vascular access had the highest prevalence of peripheral arterial disease, which was associated with increased mortality; however, the most reliable risk factor for death was decreased renal function, predominantly, but not solely, found in patients with chronic vascular access. Although this group included most patients on dialysis, outcomes of IE surgery for patients on dialysis are still better than medical management.[10] Tricuspid valve replacements were performed at similar rates across predisposing condition groups. The higher mortality in these patients may be explained by the burden of disease present at operation: Patients with extensive tricuspid valve destruction likely had extensive pulmonary emboli, persistent sepsis, and systemic effects of right heart failure. Although time from infection to surgery was not available, we believe earlier surgery in these patients may have limited disease progression, increased tricuspid valve repairs, and resulted in better outcomes.

Infective Endocarditis Relapse/Recurrence

Relapse of IE should be rare. Its most important risk factor is incomplete debridement of the valve[13]; removing the source of bacteremia is essential. Dental evaluation, appropriate drainage of abscesses, and other means of source control are important in preventing early relapse. Using medication-assisted treatment for injection drug users, placing epicardial pacemaker leads, and meticulous arteriovenous fistula cannulation hygiene during dialysis are examples of reinfection risk mitigation.

Recurrent IE was infrequent in our cohort, with most occurrences in injection drug users. Although neither history of IE nor valve replacement at index operation was a significant risk factor for recurrence, limited sample size may have affected these findings. Prosthetic valves and injection drug use remain complementary risk factors; injection drug use leads to bacteremia, and prosthetic valves provide a better adhesion site for organisms than native valves.[33] Injection drug users who underwent tricuspid valve replacement at index operation were those who had a prior prosthetic tricuspid valve or had such extensive native valve damage that the surgeon deemed replacement necessary. If seen today, some of these patients may have had their native valves reconstructed instead of replaced. Nonetheless, based on experience with mitral valve reconstructions for IE, infection resistance and durability of valve reconstruction need further study.

Given that 87% of our patients, including 76% of injection drug users, did not develop recurrent IE during follow-up, risks of recurrence or reoperation are important, but should not impede a potentially life-saving operation.

Study Strengths and Limitations

Although one of the largest surgical series of right-sided IE, it represents a single, quaternary-care referral center more likely to receive patients with advanced and complex disease. The cohort included only patients selected for operation and thus by design was biased toward those with severe IE deemed to require surgery and healthy enough to tolerate it. Surgeons and IE care teams perform a large volume of IE operations annually, and results may not be generalizable.

Medically treated patients were not investigated in the present study. The majority of our IE patients are referrals for surgery, but many are deemed not to require an operation or to be too sick to have one. Therefore, we limited our study to surgically managed right-sided IE.

CONCLUSIONS

Patients undergoing operation for right-sided IE demonstrate substantial variability based on predisposing conditions and comorbid risk factors, but have tolerable short- and long-term mortality and low risk for relapse/recurrence. Patient-specific factors, such as poor renal function and mitral valve IE, increased the risk of mortality, but predisposing condition did not. Tricuspid valve replacement was a risk factor for late mortality and should be avoided when possible. An individualized approach to patient selection and early operations in those with right-sided IE may improve patient outcomes.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: infective endocarditis, right-sided, tricuspid valve, pulmonary valve, etiology

APPENDIX E1. VARIABLES CONSIDERED IN THE MULTIVARIABLE ANALYSES

Endocarditis Details

Valves affected (tricuspid, pulmonary, mitral, aortic, right side only), prosthetic or native valve, invasive disease, organism.

Predisposing Condition

Injection drug use, cardiac implantable device, chronic vascular access, other/none.

Persuasive Clinical Findings

Severe valvular regurgitation, right heart failure, left heart failure, septic emboli, large vegetations, medical failure/uncontrolled infection, valve destruction/damage, prosthetic valve dehiscence, fistula/abscess/pseudoaneurysm, patent foramen ovale/atrial septal defect/ventricular septal defect, worsening heart block/conduction defect.

Microorganism

Staphylococcus aureus, coagulase-negative staphylococcus, enterococcus, viridans group streptococcus, gram-positive cocci not further identified, polymicrobial, fungus, pathogen not identified, other.

Demographics

Age (y), sex, race (black, white, other), height (cm), weight (kg), body surface area (m^2), body mass index (kg/m^2).

Clinical Status

New York Heart Association functional class (I-IV), emergency operation.

Preoperative Echocardiographic Findings

Aortic valve regurgitation grade, mitral valve regurgitation grade, tricuspid valve regurgitation grade, aortic valve stenosis, mitral valve stenosis, tricuspid valve stenosis, left ventricular (LV) ejection fraction (%), LV inner diastolic diameter (cm), LV inner systolic diameter (cm), right ventricular systolic pressure (mmHg), left atrial diameter (cm), posterior wall thickness (cm).

Cardiac Comorbidity

Preoperative atrial fibrillation, number of prior cardiac operations, heart failure, complete heart block, prior myocardial infarction.

Noncardiac Comorbidity

Prior stroke, pharmacologically treated diabetes (insulin and noninsulin dependent), history of hypertension, peripheral arterial disease, history of smoking, chronic obstructive pulmonary disease, renal failure requiring dialysis, blood urea nitrogen (mg/dL), creatinine (mg/dL), creatinine clearance (mL/min), glomerular filtration rate (mL/min/1.73 m^2), bilirubin (mg/dL), cholesterol (total, high-density lipoprotein, low-density lipoprotein), triglycerides (mg/dL), hematocrit (%).

Surgical Procedure

Concomitant coronary artery bypass grafting, concomitant aortic surgery, tricuspid valve replacement, tricuspid valve repair/reconstruction.

Experience

Date of operation (days from January 1, 2002, to index operation).

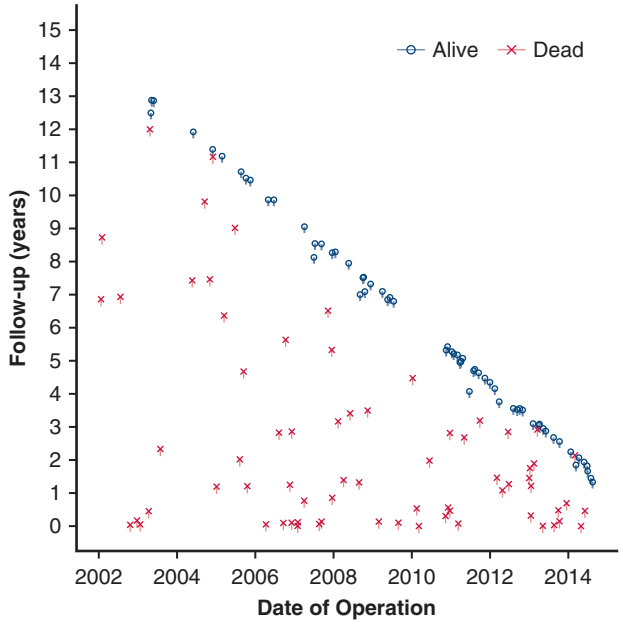


FIGURE E1. Chronogram of follow-up of patients undergoing surgery for right-sided IE. *Red x's* denote deaths, and *blue circles* denote patients alive at follow-up.

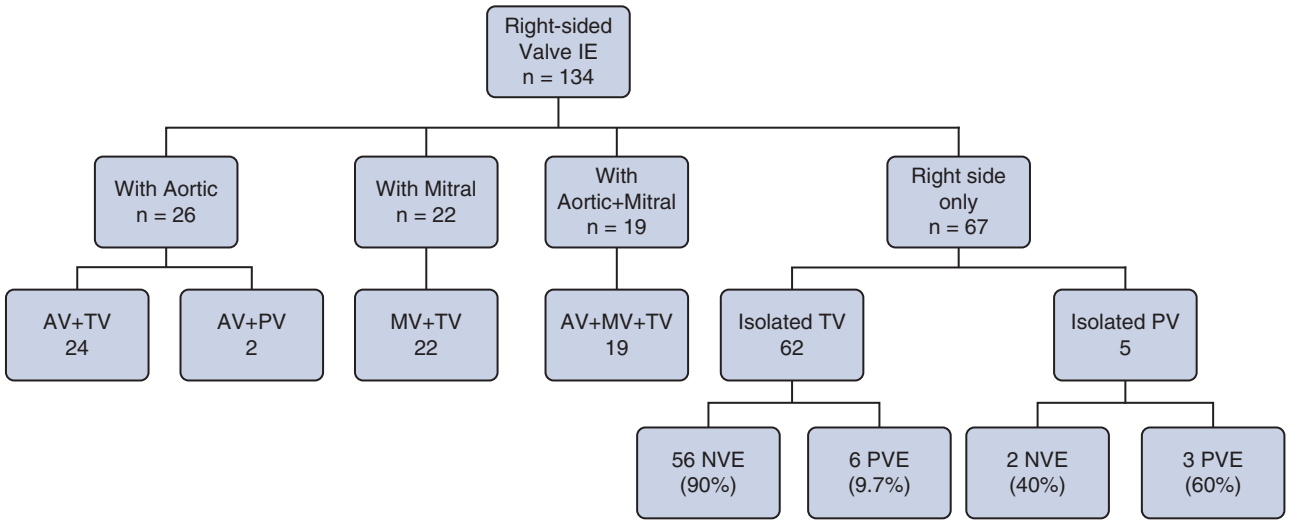


FIGURE E2. CONSORT-style diagram of study cohort. *IE*, Infective endocarditis; *AV*, aortic valve; *TV*, tricuspid valve; *PV*, pulmonary valve; *MV*, mitral valve; *NVE*, native valve endocarditis; *PVE*, prosthetic valve endocarditis.

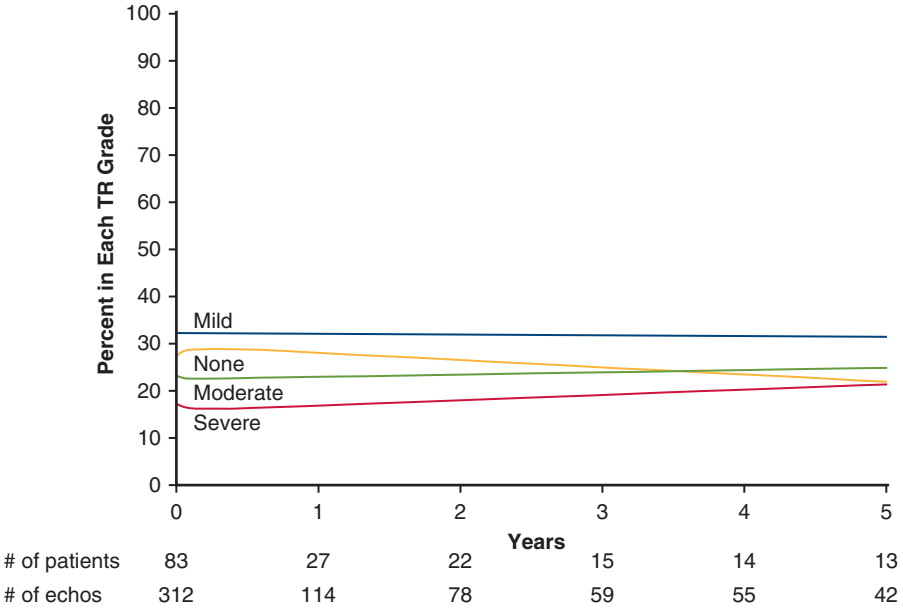


FIGURE E3. Postoperative tricuspid regurgitation (*TR*) in those receiving tricuspid repair/reconstruction for right-sided IE. Lines depict prevalence of TR in each grade based on a linear mixed model. *Yellow line* is no TR, *blue line* is mild TR, *green line* is moderate TR, and *red line* is severe TR.

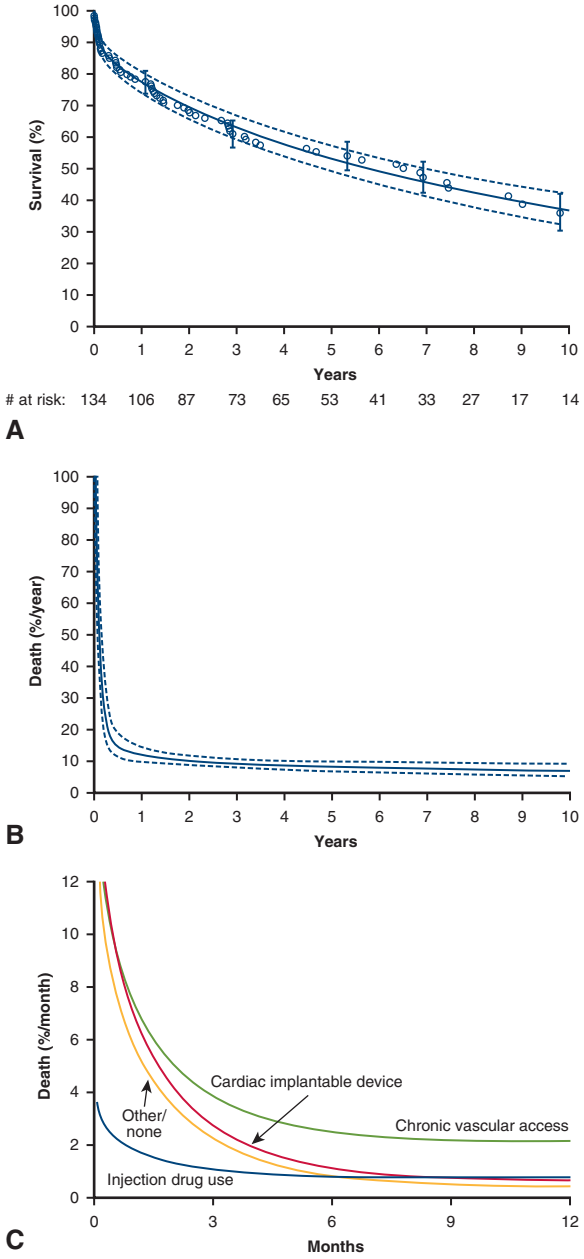
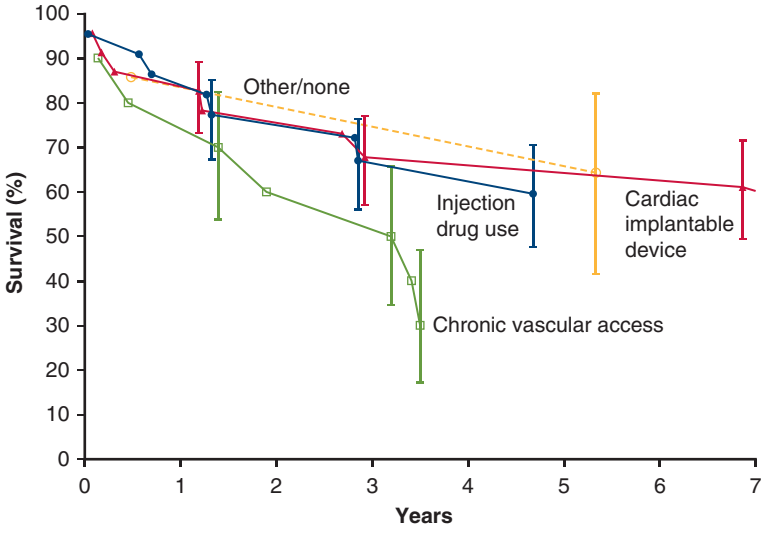
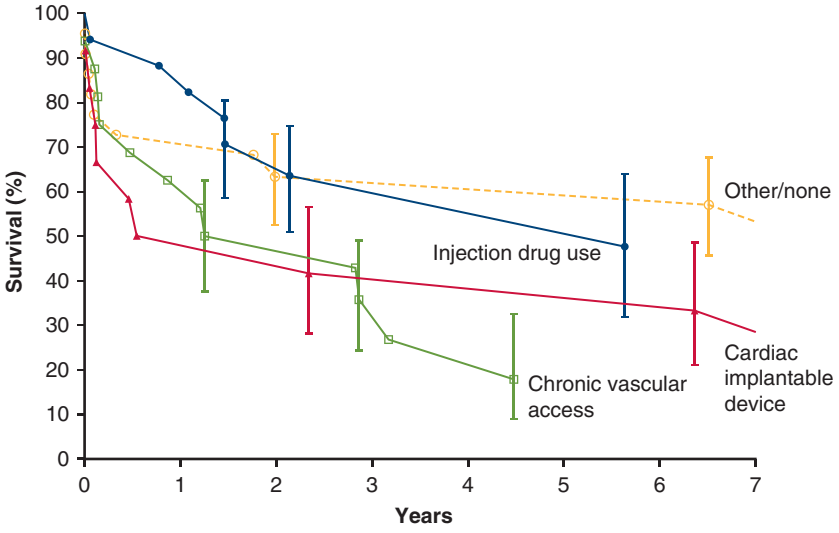


FIGURE E4. Survival after surgery for right-sided IE. A, *Solid line* is parametric estimate enclosed within a 68% dashed confidence band equivalent to ±1 standard error, each *circle* represents a death, and *vertical bars* represent 68% confidence limits of Kaplan-Meier estimates. B, Hazard function for death. *Solid line* is parametric estimate enclosed within a 68% dashed confidence band equivalent to ±1 standard error. C, Hazard function for death within first 12 months according to predisposing condition. Injection drug use group is denoted by *blue line*, cardiac implantable device group is denoted by *red line*, chronic vascular access group is denoted by *green line*, and other/none group is denoted by *yellow line*.



# at risk								
Drug use	22	20	17	14	1	7	6	6
CID	23	21	28	14	14	12	11	9
Vasc. access	10	9	7	7	–	–	–	–
Other/none	7	6	6	6	5	5	4	3

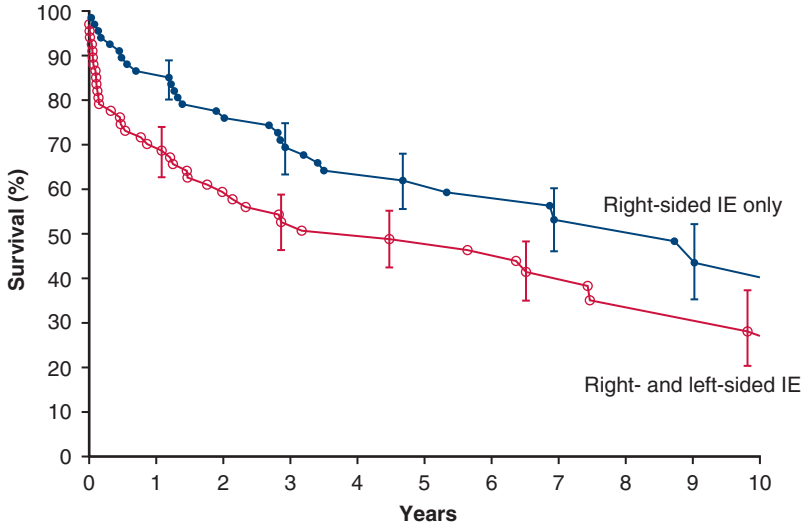
A



# at risk								
Drug use	17	16	11	9	9	6	4	2
CID	12	7	6	6	6	6	5	5
Vasc. access	16	11	8	5	4	3	2	1
Other/none	22	17	14	13	12	12	11	10

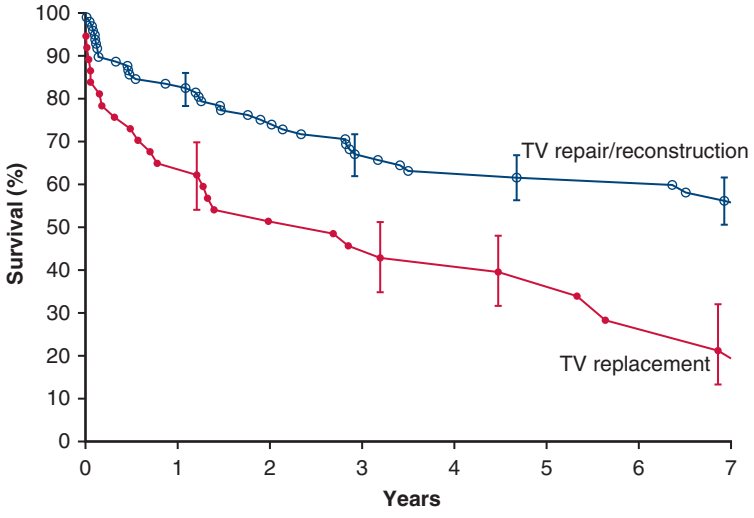
B

FIGURE E5. Survival of patients undergoing surgery for right-sided IE according to predisposing condition. Each *symbol* represents a death and *vertical bars* 68% confidence limits equivalent to ±1 standard error. Injection drug use is denoted by *blue lines* and *filled circles*, CID is denoted by *red lines* and *triangles*, chronic vascular access is denoted by *green lines* and *squares*, and other/none is denoted by *yellow dashed lines* and *open circles*. A, Isolated tricuspid valve IE. B, Right- and left-sided IE. *CID*, Cardiac implantable device.



# at risk						
RSIE only	67	51	33	22	13	10
Right + left	67	37	28	20	11	3

FIGURE E6. Survival after surgery for right-sided and right- and left-sided IE. Format is as in Figure E4. Right-sided IE-only group is denoted by *blue line* and *filled circles*, and right- and left-sided IE group by *red line* and *open circles*. *IE*, Infective endocarditis; *RSIE*, right-sided IE.



# at risk								
Repair/reconstruct.	93	82	69	52	50	42	42	30
Replace	37	25	20	17	16	13	6	4

FIGURE E7. Survival after tricuspid valve (*TV*) repair/reconstruction or replacement in entire cohort. Format is as in Figure E4. TV repair/reconstruction is denoted by *blue line* and *open circles*, and TV replacement by *red line* and *filled circles*.

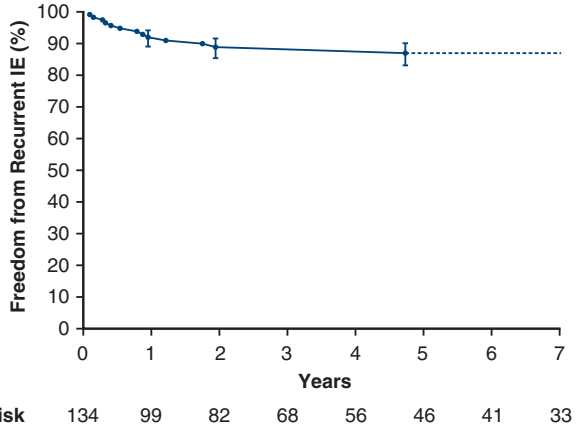


FIGURE E8. Freedom from relapse/recurrent IE after surgery for right-sided IE in overall cohort. Format is as in Figure E4. *IE*, Infective endocarditis.

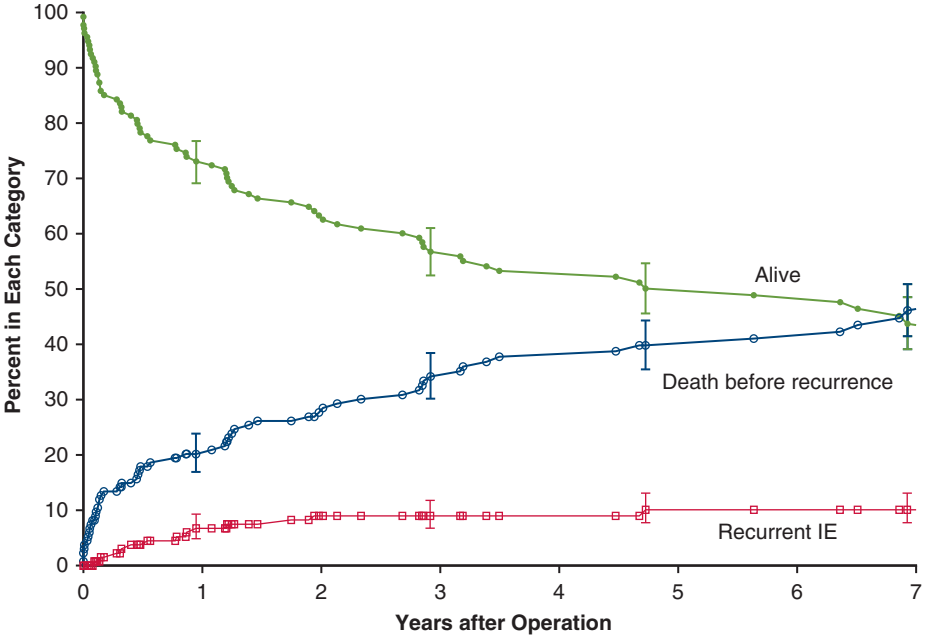
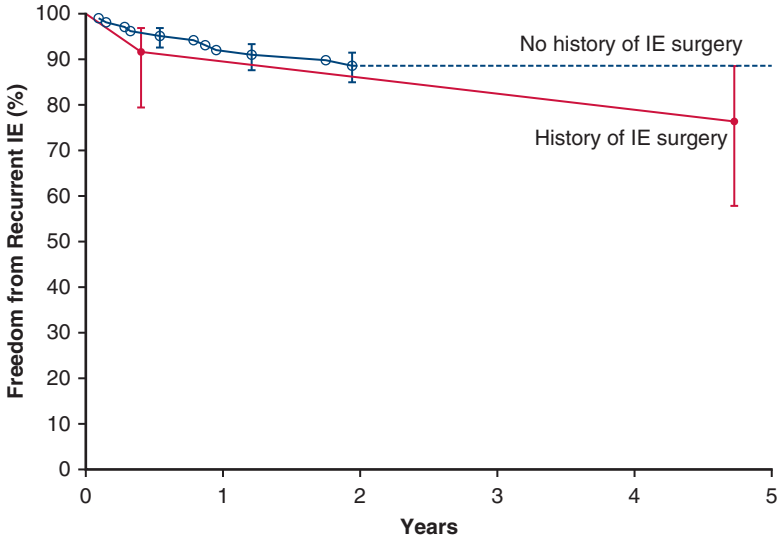


FIGURE E9. Competing risks of death and relapse/recurrent endocarditis after surgery for right-sided IE. Format is as in Figure E4. *IE*, Infective endocarditis.



 # at risk

History of IE surgery						
No	120	89	74	62	50	41
Yes	14	11	9	7	7	6

FIGURE E10. Freedom from relapse/recurrent IE stratified by history of IE surgery at index operation. Format is as in Figure E4. History of IE surgery is denoted by *red line* and *filled circles*, and no history of IE surgery by *blue line* and *open circles*. *IE*, Infective endocarditis.

TABLE E1. Other/none predisposing condition group characteristics and valve involvement

Patient No.	If valve infected, what type of valve?				Invasion from left to right*	Index procedures	Prior surgery for congenital heart anomaly	History of IE	Microbiology	Other risk factors for IE
	Tricuspid	Pulmonary	Mitral	Aortic						
1	Native	–	–	–	–	TVr	No	No	CoNS	–
2	–	Native	–	Native	No	AVR, PVr, VSD closure	No	No	*S bovis*	Surgical site infections, VSD
3	Native	–	–	–	–	TVr	No	No	*S aureus*	Lower leg abscess s/p amputation
4	Native	–	Native	Native	No	AVR, MVR, TVr	No	No	*A defectiva*	Recent medical procedures
5	–	Allo	–	Auto	No	Allo PVR, AVr, TVr	Yes: Ross procedure	No	*S aureus*	–
6	Native	–	–	Native	No	AVR, TVr	No	No	*E faecalis*	Recent vascular surgery
7	Native	–	–	Prosth	Yes	Allo AVR, TVr	No	No	*E faecalis*	Recent medical procedures
8	Native	–	Native	–	No	MVr, TVr, VSD closure	No	No	*S pyogenes*	Unrepaired VSD
9	Native	–	Native	Prosth	Yes	Allo AVR, TVr, MVr	No	No	*S aureus*	–
10	Native	–	Prosth	–	No	MVR, TVr	No	No	CoNS	Recent abdominal surgery
11	Native	–	–	Native	No	AVR, TVr, VSD closure	No	No	CoNS	Unrepaired VSD
12	–	Allo	–	–	–	Allo PVR	No	Yes	PNID	Previous Ross procedure for AV IE
13	Native	–	–	Native	No	AVR, TVr	No	No	*S aureus*	Lower leg abscess s/p amputation
14	–	Native	–	–	–	PVr, PFO closure	Yes: VSD repair	No	*A xylosoxidans*	Unrepaired PFO
15	Native	–	Native	Native	No	AVR, TVR, MVr	No	No	*S pneumoniae*	–
16	Native	–	Native	Native	Yes	Allo AVR, MVR, TVr	No	No	*B henslae*	Aortic stenosis
17	Native	–	–	Native	No	Allo AVR, TVr	No	No	*S aureus*	–
18	Native	–	–	Native	No	AVR, TVr	No	No	PNID	Septic miscarriage
19	–	Native	–	–	–	Allo PVR	No	No	CoNS	Penetrating sternal wire in RVOT
20	–	Prosth	–	–	–	Allo PVR	Tetralogy of Fallot; RVOT conduit, LVOT repair	No	CoNS	–
21	Prosth	–	–	–	–	TVR	No	Yes: TVR for IE	*S aureus*	Recent gynecologic surgery
22	Native	–	Native	Native	Yes	AVR, MVR, TVR	No	No	CoNS	–
23	Native	–	Native	Prosth	Yes	Allo AVR, TVr, MVr	No	No	*S aureus*	–
24	Native	–	–	–	–	TVr, PFO, and VSD closure	No	No	PNID	Unrepaired VSD, PFO
25	Native	–	–	–	–	TVR	No	No	*P vulgaris*	Gangrenous cholecystitis
26	Native	–	–	–	–	TVr, ASD closure	No	No	CoNS	Unrepaired ASD

(Continued)

TABLE E1. Continued

Patient No.	If valve infected, what type of valve?				Invasion from left to right*	Index procedures	Prior surgery for congenital heart anomaly	History of IE	Microbiology	Other risk factors for IE
	Tricuspid	Pulmonary	Mitral	Aortic						
27	Native	–	–	Prosth	Yes	Allo AVR, TVr	No	No	VGS	AVR, hemi-arch replacement for ascending aortic aneurysm
28	Native	–	–	Native	No	AVR, TVR	No	No	*C hominis*	–
29	Native	–	Native	Native	No	AVR, MVR, TVr	No	No	*E faecalis*	Immunosuppression
30	Native	–	–	–	–	TVr, PFO closure	No	No	*S aureus*	Unrepaired PFO
31	Native	–	–	Native	No	Allo AVR, TVr, VSD closure	No	No	*S pneumoniae*	Unrepaired repaired VSD
32	Pros	–	Prosth	Prosth	Yes	Allo AVR, MVR, TVR	No	No	PNID	Triple valve replacement for Libman-Sacks endocarditis
33	Native	–	Native	Prosth	Yes	Allo AVR, MVr, TVr	No	No	CoNS	–

AVR, Aortic valve replacement; *PVr*, pulmonary valve repair; *VSD*, ventricular septal defect; *Allo*, allograft; *Auto*, autograft; *PVR*, pulmonary valve replacement; *AVr*, aortic valve repair; *TVr*, tricuspid valve repair; *PNID*, pathogen not identified; *IE*, infective endocarditis; *PFO*, patent foramen ovale; *CoNS*, coagulase-negative staphylococcus; *RVOT*, right ventricular outflow tract; *Prosth*, prosthetic; *LVOT*, left ventricular outflow tract; *PV*, pulmonary valve; *VGS*, viridans group streptococcus. *Evidence of invasive fistula tract from a left-sided infection to right-sided valves.

TABLE E2. Characteristics of patients undergoing surgery for pulmonary valve infective endocarditis

Patient No.	If valve infected, what type of valve?				Predisposing condition	Index procedures	Prior surgery for congenital heart anomaly	History of IE	Microbiology	Other risk factors for IE
	Tricuspid	Pulmonary	Mitral	Aortic						
1	–	Native	–	Native	Other/none	AVR, PVr, VSD closure	No	No	*S bovis*	Surgical site infections, VSD
2	–	Allo	–	Auto	Other/none	Allo PVR, AVr, TVr	Ross procedure	No	*S aureus*	–
3	–	Allo	–	–	Other/none	Allo PVR	No	Yes	PNID	Previous Ross procedure for IE
4	–	Native	–	–	Other/none	PVr, PFO closure	VSD repair	No	*A xylosoxidans*	Unrepaired PFO
5	–	Native	–	–	Other/none	Allo PVR	No	No	CoNS	Penetrating sternal wire in RVOT
6	–	Prosth	–	–	Other/none	Allo PVR	Tetralogy of Fallot; RVOT conduit, LVOT repair	No	CoNS	–
7	–	Allo	–	–	Injection drug use	Allo PVR	Congenital PV stenosis: allograft RVOT replacement	No	VGS	–

AVR, Aortic valve replacement; *PVr*, pulmonary valve repair; *VSD*, ventricular septal defect; *Allo*, allograft; *Auto*, autograft; *PVR*, pulmonary valve replacement; *AVr*, aortic valve repair; *TVr*, tricuspid valve repair; *PNID*, pathogen not identified; *IE*, infective endocarditis; *PFO*, patent foramen ovale; *CoNS*, coagulase-negative staphylococcus; *RVOT*, right ventricular outflow tract; *Prosth*, prosthetic; *LVOT*, left ventricular outflow tract; *PV*, pulmonary valve; *VGS*, viridans group streptococcus.

TABLE E3. Characteristics of patients undergoing surgery for fungal right-sided infective endocarditis

Patient No.	If valve infected, what type of valve?				Predisposing condition	Index procedures	Microbiology	Long-term fungal suppression	Outcomes
	Tricuspid	Pulmonary	Mitral	Aortic					
1	Native	–	–	–	Injection drug use	TVR	*C albicans*	Fluconazole	Died without recurrence 16 mo after index operation
2	Prosth	–	–	–	Injection drug use	TVR with pulmonary allograft	*C albicans, P aeruginosa*	None	Alive without events 56 mo after index operation
3	Native	–	–	–	Cardiac implantable device	TVr	*A flavus*	Voriconazole	Died without recurrence 36 mo after index operation
4	Repaired native	–	Prosth	–	Chronic vascular access	TVR	*C tropicalis*	None	Alive without events 42 mo after index operation

TVR, Tricuspid valve replacement; *Prosth*, prosthetic; *TVr*, tricuspid valve repair.

TABLE E4. Surgical and postoperative outcomes according to predisposing condition

Characteristics	Predisposing condition				*P*
	Injection drug use (n = 40) No. (%) or median [15th, 85th percentiles]	Cardiac implantable device (n = 35) No. (%) or median [15th, 85th percentiles]	Chronic vascular access (n = 26) No. (%) or median [15th, 85th percentiles]	Miscellaneous (n = 33) No. (%) or median [15th, 85th percentiles]	
Procedural					
Myocardial ischemic time (min)	79 [29, 138]	90 [6, 175]	102 [42, 162]	110 [44, 192]	.14
Cardiopulmonary bypass time (min)	93 [49, 179]	122 [56, 240]	141 [90, 240]	134 [63, 275]	.02
Blood products					
Intraoperative*					
Cryoprecipitate	1 (2.6)	2 (7.7)	6 (24)	6 (23)	.02
Fresh frozen plasma	8 (21)	10 (38)	12 (48)	11 (42)	.10
Platelets	11 (28)	11 (42)	17 (68)	13 (50)	.02
Red blood cells	28 (72)	16 (62)	20 (80)	22 (85)	.2
Postoperative					
Cryoprecipitate	3 (7.5)	1 (2.9)	3 (12)	3 (9.1)	.6
Fresh frozen plasma	7 (18)	6 (17)	5 (19)	7 (21)	>.9
Platelets	5 (13)	10 (29)	8 (31)	7 (21)	.2
Red blood cells	27 (68)	26 (74)	23 (88)	24 (73)	.3
Postoperative complications					
Hospital death	0 (0)	2 (5.7)	2 (7.7)	4 (12)	.18
Stroke	0 (0)	0 (0)	0 (0)	2 (6.1)	.10
Reoperation for bleeding/ tamponade	3 (7.5)	3 (8.6)	1 (3.8)	4 (12)	.7
Other noncardiac reoperation	5 (13)	4 (11)	3 (12)	5 (15)	>.9
Renal failure	1 (2.5)	8 (23)	0 (0)	8 (24)	.002
Prolonged ventilation (>24 h)	11 (28)	16 (46)	12 (46)	12 (36)	.3
Length of stay					
ICU (h)	84 [25, 208]	100 [42, 413]	135 [40, 690]	72 [24, 284]	.08
Postoperative (d)	14 [7.1, 27]	13 [8.0, 28]	17 [6.2, 40]	11 [6.3, 17]	.15
Hospital (d)	25 [13, 34]	22 [14, 46]	25 [12, 54]	19 [12, 30]	.04

ICU, Intensive care unit. *Intraoperative blood data incomplete; available in 39, 25, 26, and 26 patients, respectively.

TABLE E5. New heart block after surgery for right-sided infective endocarditis

Patient No.	Valves affected	Type of valves affected	Predisposing condition	Index procedures	Preoperative ECG	Postoperative ECG	PPM placed?
Isolated right-sided IE							
1	TV	Native	Injection drug use	TVR	ST	First-degree block	No
2	TV	Native	Injection drug use	TVR	NSR	CHB	Yes
3	TV	Native	Injection drug use	TVR	ST, RBBB	CHB	Yes
4	TV	Prosth	Other/none	TVR	Incomplete RBBB	CHB	Yes
5	TV	Native	Injection drug use	TVR	ST	CHB	Yes
6	TV	Prosth	Injection drug use	TVR	ST, RBBB	CHB	Yes
7	TV	Native	Other/none	TV repair, VSD closure	NSR	Intermittent CHB	Yes
8	TV	Native	Other/none	TVR	NSR	CHB	Yes
9	TV	Native	Injection drug use	TVR	NSR, Incomplete RBBB	CHB	Yes
Left- and right-sided IE							
1	PV, AV	All native	Other/none	AVR, PVr, VSD closure	NSR	CHB	Yes
2	TV, AV, MV	All native	Other/none	AVR, MVr, TVR	ST	CHB	Yes
3	TV, AV, MV	All native	Other/none	AVR, MVr, TVr	NSR	CHB	Yes

ECG, Electrocardiogram; *PPM*, permanent pacemaker; *IE*, infective endocarditis; *TV*, tricuspid valve; *TVR*, tricuspid valve replacement; *ST*, sinus tachycardia; *NSR*, normal sinus rhythm; *CHB*, complete heart block; *RBBB*, right bundle branch block; *Prosth*, prosthetic; *VSD*, ventricular septal defect; *PV*, pulmonary valve; *AV*, aortic valve; *AVR*, aortic valve replacement; *PVr*, pulmonary valve repair; *MV*, mitral valve; *MVr*, mitral valve repair; *TVr*, tricuspid valve repair.

TABLE E6. Incremental risk factors for late mortality after surgery for right-sided infective endocarditis

Factor	Coefficient ± SE	*P*	Reliability (%)*
eGFR†	−0.67 ± 0.18	.0002	90
Mitral valve affected	0.73 ± 0.29	.01	58
Tricuspid valve replacement	0.90 ± 0.28	.001	71
Peripheral arterial disease	1.3 ± 0.33	<.0001	61
Predisposing condition			
Injection drug use	0.14 ± 0.38	.7	Forced in
Chronic vascular access	0.011 ± 0.29	.9	Forced in
Cardiac implantable device	0.43 ± 0.37	.2	Forced in

SE, Standard error; *eGFR*, estimated glomerular filtration rate. *Percent of times factor appeared in 1000 bootstrap models. †Logarithmic transformation.

TABLE E7. Details of relapse/reinfection after surgery for right-sided infective endocarditis

Patient No.	Time from index operation (mo)	Predisposing condition	Index procedures	Reoperation procedures	Index operation organism	Recurrence organism	Relapse or reinfection
1	1	Other/none	AVR, MVr, TVr	Allo AVR, Fistula repair	Pathogen not identified	Pathogen not identified	Likely relapse*
2	1	Injection drug use	TVr	Allo AVR, TVr, PFO closure	Pathogen not identified	Pathogen not identified	Likely relapse*
3†	3	Injection drug use	MVr, TVr	MVR, TVR	*S aureus*	*S aureus*	Relapse
4	3	Injection drug use	TVR	TVR	*S aureus*	*S aureus*	Relapse
5	4	Injection drug use	AVr, TVR	AVr, TVR	MRSA	MSSA	Reinfection
6	6	Cardiac implantable device	MVr, TVr	MVR	*M chenolae-abscessus complex*	*M chenolae-abscessus complex*	Relapse
7	9	Other/none	Allo AVR, TVr	Allo AVR	*E faecalis*	*C krusei*	Reinfection
8‡	10	Injection drug use	MVR, TVr	–	*S aureus*	*E faecium*	Reinfection
9	11	Injection drug use	TVR	TVR	*S aureus*	*E faecalis*	Reinfection
3†	13	Injection drug use	MVR,TVR	MVR, TVR	*S aureus*	*E fecalis*	Reinfection
10	14	Injection drug use	MVR, TVr	MVR	*S aureus*	*R mucilaginosa*	Reinfection
11	20	Injection drug use	MVR, TVr	MVR, TVr	*S aureus*	*C albicans*	Reinfection
12‡	23	Injection drug use	TVr	–	*S aureus*	*P aeruginosa*	Reinfection
13	56	Other/none	TVR	Allo AVR, TVR	*S aureus*	*S aureus*	Reinfection

AVR, Aortic valve replacement; *MVr*, mitral valve repair; *TVr*, tricuspid valve repair; *Allo*, allograft; *PFO*, patent foramen ovale; *MVR*, mitral valve replacement; *TVR*, tricuspid valve replacement; *AVr*, aortic valve repair; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *MSSA*, methicillin-sensitive *Staphylococcus aureus; TV*, tricuspid valve. *In 2 cases, the pathogen was not identified at index operation or reoperation; however, reoperation was performed within 1 month of index operation. These were deemed "likely relapse." †Patient was treated for recurrent IE twice at this institution. ‡All patients underwent reoperation for recurrent IE except #8 and #12, who were treated medically.