

# Percutaneous Pacemaker and Implantable Cardioverter-Defibrillator Lead Extraction in 100 Patients With Intracardiac Vegetations Defined by Transesophageal Echocardiogram

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## Objectives

We describe the feasibility, safety, and clinical outcomes of percutaneous lead extraction in patients at a tertiary care center who had intracardiac vegetations identified by transesophageal echocardiogram.

## Background

Infection in the presence of intracardiac devices is a problem of considerable morbidity and mortality. Patients with intracardiac vegetations are at high risk for complications related to extraction and protracted clinical courses. Historically, lead extraction in this cohort has been managed by surgical thoracotomy.

## Methods

We analyzed percutaneous lead extractions performed from January 1991 to September 2007 in infected patients with echocardiographic evidence of intracardiac vegetations, followed by a descriptive and statistical analysis.

## Results

A total of 984 patients underwent extraction of 1,838 leads; local or systemic infection occurred in 480 patients. One hundred patients had intracardiac vegetations identified by transesophageal echocardiogram, and all underwent percutaneous lead extraction (215 leads). Mean age was 67 years. Median extraction time was 3 min per lead; median implant duration was 34 months. During the index hospitalization, a new device was implanted in 54 patients at a median of 7 days after extraction. Post-operative 30-day mortality was 10%; no deaths were related directly to the extraction procedure.

## Conclusions

Patients with intracardiac vegetations identified on transesophageal echocardiogram can safely undergo complete device extraction using standard percutaneous lead extraction techniques. Permanent devices can safely be reimplemented provided blood cultures remain sterile. The presence of intracardiac vegetations identifies a subset of patients at increased risk for complications and early mortality from systemic infection despite device extraction and appropriate antimicrobial therapy. (*J Am Coll Cardiol* 2010;55:886–94) © 2010 by the American College of Cardiology Foundation

Landmark trials have expanded the indications for cardiac rhythm management (CRM) devices (1–4). The consequences of device-related complications are well documented (5–8). Infection of CRM devices has been reported in 0.8% to 19.9% of patients (9). Mortality rates for untreated patients are as high as 66% compared with 18%

for patients treated with antibiotics and device removal (5,7,8,10–12). Eradication of device-related infection requires complete system removal, given the morbidity and mortality associated with antibiotics alone or partial device removal (5,7,11,13–16).

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Patients with infected devices and intracardiac vegetations represent a high-risk population, the incidence of which is difficult to determine from available studies. Arber et al. (17) documented the incidence of endocarditis with device infection to be 9.4%. Patients with vegetations >1 cm have historically been managed with extraction through open thoracotomy due to potential for septic embolization

and hemodynamic compromise (6,10,14,18–20). A review of the literature reveals limited data describing the efficacy and safety of percutaneous lead extraction in this subset (6,14,19–21).

In this study, we document the incidence of intracardiac vegetations in patients with CRM devices referred to an extraction center and evaluate the safety and efficacy of lead extraction in this high-risk population. Further, we examine the safety and clinical outcomes associated with reimplantation of a new CRM device.

## Methods

**Study population.** Our institution's institutional review board approved the study. A comprehensive database is maintained for all patients undergoing lead extraction. Patients who had objective evidence of device-related infection and echocardiographic evidence of intracardiac vegetations and underwent device extraction at our institution from January 1991 to September 2007 were included in this study. Office charts and hospital records were reviewed to gather pertinent clinical information.

**Control population.** All patients who underwent lead extraction in 2004 without evidence of intracardiac vegetations served as a reference population. We compared implant duration and extraction times between the 2004 cohort and our study population. To standardize comparisons, only data from the first lead extracted in each patient were used.

**Definitions.** Device-related infection was defined by signs of local pocket inflammation, generator or lead erosion, or positive blood cultures. Device-related endocarditis was defined according to the modified Duke criteria (22). Patients with a diagnosis of definite or possible endocarditis were included. Intracardiac vegetation was defined as a discrete, echogenic, oscillating mass found on a valve, lead, or endocardial surface and confirmed in multiple views by echocardiography. Echocardiograms were reviewed by an echocardiographer and electrophysiologist to determine vegetation size and location and to distinguish true vegetation from false echodensities. In 23 cases, echocardiogram images were not available for review and information was obtained from study reports.

Implant duration was the time between initial lead implantation to the time it was extracted. Lead extraction time was defined as the duration from the time when the head of the lead was cut off until its complete removal. Extraction time for leads removed with traction only was the time from removal of the anchoring sleeve to complete removal.

**Current protocol.** Because of potential for septic embolization, pre-operative transesophageal echocardiography (TEE) is used to risk stratify patients. After extraction, TEE is performed in all patients before device reimplantation. In addition, intraoperative intracardiac echocardiography (ICE) may be used to assess lead fibrosis and vegetation stability and to monitor for complications. All patients undergo serial blood cultures and intravenous

antibiotic therapy according to sensitivities of isolated organisms and the recommendations of an infectious disease consultation. Temporary transvenous pacing wires are placed when indicated despite presence of vegetations until a permanent system can safely be implanted.

Standard methods for percutaneous lead extraction are utilized at the discretion of the extracting physician (20,23–28). An electrosurgical dissection sheath (Cook Corp., Vandergrift, Pennsylvania) or Excimer laser (Spectranetics Corp., Colorado Springs, Colorado) is used to extract heavily fibrotic leads. Extensive surgical debridement of the pocket is performed using electrocautery and blunt dissection. Timing of device reimplantation is based primarily on sterility of blood cultures, but also on resolution of vegetations. Reimplantation is usually performed on the contralateral side. In select cases, an ipsilateral lateral subpectoral location may be used depending on the extent of pocket infection.

Patients are followed up in the outpatient office after extraction. In cases when patients were referred back to their primary institution, the primary cardiologist or internist was contacted for information regarding the patient's medical progress.

**Statistical analysis.** Mean and SD and/or median and interquartile ranges (IQRs) summarize continuous demographic data. The Wilcoxon test compares implant durations and extraction times in the study population to those of the 2004 reference population. Kaplan-Meier curves and product-limit life-table estimates analyzed the time from lead extraction to reimplantation of a new lead, stratified into groups by microorganism type. Both log-rank and Wilcoxon tests were used to compare those groups with respect to time to reimplantation. All analyses used a significance level of 0.05.

## Results

**Study population.** Figure 1 represents the patients referred for lead extraction from January 1991 through September 2007. Nine hundred eighty-four patients underwent extraction, and 1,838 leads were removed. Four hundred eighty patients (49%) required device extraction of 1,000 leads for systemic or localized pocket infection. One hundred patients had echocardiographic evidence of intracardiac vegetations (Figs. 2A and 2B), and they represent 10% of our total extraction population (Table 1). Vegetations were found on leads in 56 cases and valves in 35 cases; in 9 cases, this information was not available. Vegetations ranged in size from 0.2 to 4.0 cm in largest longitudinal diameter; the mean diameter was 1.6 cm. All patients underwent com-

## Abbreviations and Acronyms

CI = confidence interval

CNS = coagulase-negative *Staphylococcus* species

CRM = cardiac rhythm management

ICE = intracardiac echocardiography

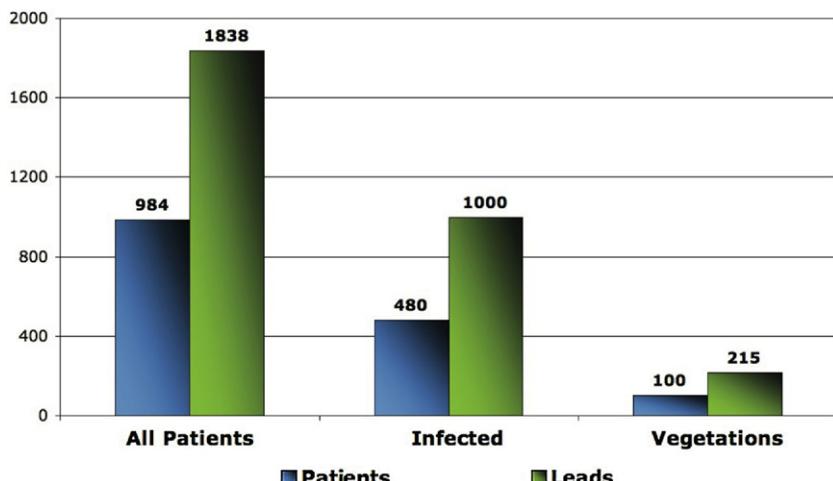
IQR = interquartile range

MRSA = methicillin-resistant *Staphylococcus aureus*

MSSA = methicillin-sensitive *Staphylococcus aureus*

SCD = sudden cardiac death

TEE = transesophageal echocardiogram



**Figure 1 Extraction Population**

Total number of patients and leads from January 1991 to September 2007, including subsets with device-related infection and intracardiac vegetations.

plete device extraction in our electrophysiology laboratory; 215 leads were removed using standard percutaneous techniques. No patients required surgical extraction. Seventy-one patients were men. Mean age was  $67 \pm 15$  years (age range 22 to 92 years).

**Microbiology.** Figure 3 depicts the infectious pathogens isolated from cultures. The most common infectious organisms were methicillin-resistant *Staphylococcus aureus* (MRSA) and methicillin-sensitive *Staphylococcus aureus* (MSSA), isolated from 34 and 25 cultures, respectively. Other organisms included coagulase-negative *Staphylococcus* species (CNSS) ( $n = 14$ ), *Enterococcus faecalis* ( $n = 4$ ), *Streptococcus* species ( $n = 4$ ), vancomycin-resistant *Enterococcus* ( $n = 1$ ), *Citrobacter* ( $n = 1$ ), and *Candida* species ( $n = 1$ ). Sixteen patients had negative blood cultures despite having evidence of endocarditis. Five of these patients had pocket tissue cultures that were positive, including MRSA in 1 patient, MSSA in 2 patients, and CNSS in 2 patients.

**Implant duration and extraction times.** Implant duration in the study population ranged from 1 to 300 months (mean  $50.9 \pm 52.8$  months, median 32.5 months, IQR 61 months). Extraction times ranged from 1 to 187 min (mean  $11.2 \pm 21.9$  min, median 3 min, IQR 13 min). Implant duration for the first lead extracted from each patient in the study population,  $54.4 \pm 56.8$  months (median 34 months, IQR 68.5 months,  $n = 99$ ), did not differ from that of the 2004 reference population,  $40.2 \pm 45.3$  months (median 24 months, IQR 36.5 months,  $n = 66$ ;  $p = 0.095$  by Wilcoxon test). Extraction time for the study population,  $10.8 \pm 16.8$  min (median 4 min, IQR 15 min,  $n = 99$ ), did not differ from that of the reference population,  $5.3 \pm 6.3$  min (median 1 min, IQR 6 min,  $n = 66$ ;  $p = 0.067$  by Wilcoxon test).

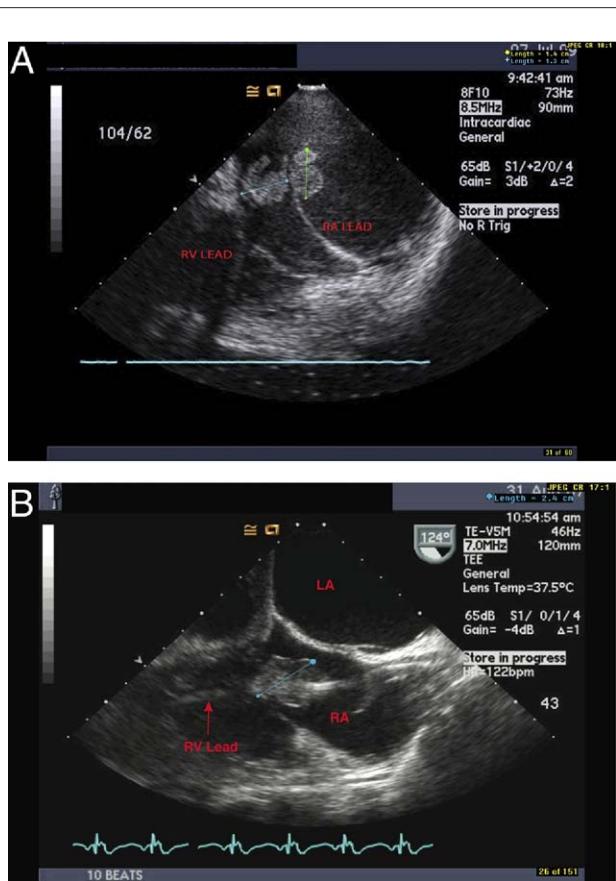
**Reimplantation of a new device.** Fifty-four (54%) patients were reimplanted with a new device during hospitalization

(Fig. 4). Two of these patients underwent reimplantation of epicardial systems due to persistent vegetations. Median time to reimplantation was 7 days (mean 11 days). Life-table analysis of time to reimplantation disclosed median times of 7 (95% confidence interval [CI]: 6 to 16) days for patients with negative blood cultures, 8 (95% CI: 7 to undefined) days for patients whose culture results were positive for CNSS, 13 (95% CI: 7 to 27) days for MSSA, and 14 (95% CI: 7 to 60) days for MRSA. The undefined upper limit for CNSS was obtained from a final censored observation. Both the log-rank test ( $p = 0.3096$ ) and the Wilcoxon test ( $p = 0.5120$ ) demonstrated no impact of culture result on time to reimplantation.

**Follow-up and clinical outcomes.** Follow-up was available for 71 patients (Fig. 5). Twenty-nine patients were lost to follow-up because of their diverse locations of origin. The average follow-up was 438 days (median 150 days).

Forty-six patients were not reimplanted during the hospitalization. Four patients were transferred back to their primary institution after device extraction. Eighteen patients were not reimplanted because of persistent systemic infection. Two patients refused reimplantation despite a medical indication, and 2 patients were referred to hospice. One patient was not reimplanted because of metastatic cancer. Of the remaining 19 patients, 18 had no compelling indication to reimplant a permanent device. Extensive thrombosis of bilateral subclavian veins limited access in the other patient. Thirty-nine of the 46 patients (85%) were discharged in stable condition. Seven patients died during the index hospitalization, and 1 experienced a complication during lead extraction; these patients are discussed in the following text.

Fifty-four patients underwent subsequent device reimplantation. Fifty-one patients (94%) were discharged in stable condition. During follow-up, no patient had clinical



**Figure 2** ICE and TEE of Lead Vegetation

(A) Intracardiac echocardiogram (ICE) shows vegetations attached to both right ventricle (RV) and right atrium (RA) leads. (B) Transesophageal echocardiogram (TEE) of lead vegetation attached to the RV lead as it crosses the tricuspid valve. The approximate diameter is 2.4 cm. LA = left atrium.

indicators of relapsing infection that required a second extraction. Three patients died during the index hospitalization and 4 others had complications during lead extraction; these patients are discussed in the following text.

**Morbidity and mortality.** Of the 71 patients who had long-term follow-up available, 19 patients died (27%). Ten patients died during the index hospitalization, and 9 died after being discharged. Eleven patients (59%) died of persistent septicemia, 1 patient died of SCD, and 7 patients died of unknown causes but had no evidence of ongoing sepsis during follow-up. Four patients died after being reimplemented with a new device despite having sterile blood cultures and no vegetations on repeat TEE. Post-operative 30-day mortality was 10% (**Table 2**).

Five patients had complications during lead extraction. Two patients had embolization of the vegetation. In 1 of those patients, embolization occurred during attempts to snare a large vegetation before lead removal. The patient remained hemodynamically stable but had chest pain after the procedure. High-resolution computed tomography (**Fig. 6**) revealed a filling defect in the pulmonary artery. The patient underwent uncomplicated device reimplan-

tion 8 days later. A third patient required an additional procedure to snare a lead fragment that embolized to the pulmonary artery during the initial extraction. The lead was 25 years old and was completely removed in pieces because of its brittle condition. The patient experienced no clinical symptoms and underwent reimplantation 7 days later. A fourth patient had severe tricuspid regurgitation due to a flail posterior leaflet that was not present before extraction. A fifth patient had hypotension after extraction that required vasopressor support for 24 h. Subsequent echocardiogram was unrevealing, and the patient had a new device implanted 12 days later. All 5 patients were discharged in stable condition and had uneventful clinical follow-up.

## Discussion

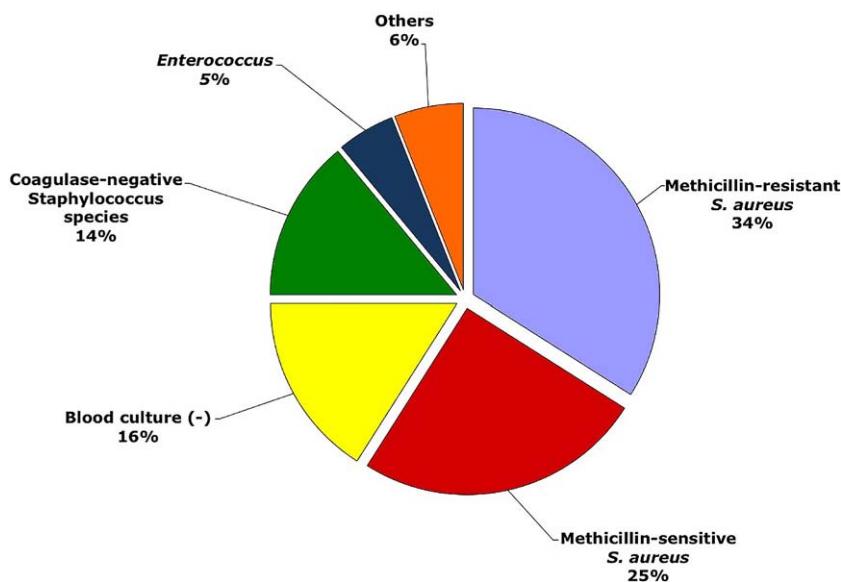
The management of device-related infection is well described, but considerable variability exists in regional management strategy. Complete hardware removal is essential to eradicate infection and prevent relapsing bacteremia. In 9 retrospective studies, the mortality rate was 41% for patients treated with antibiotics alone compared with 19% for patients receiving antibiotics and complete device removal (28).

Patients with device-related infection and intracardiac vegetations >1 cm have historically undergone surgical thoracotomy for device removal because of the potential for septic embolization. Literature supporting this management approach is limited (6,14,28,29). Our single-center experience involving this high-risk population suggests that standard endovascular percutaneous extraction of leads is both feasible and safe.

**Incidence of intracardiac vegetations.** The incidence of intracardiac vegetations comprised 10% of our entire extraction population and 21% of all patients with device-related infection. The incidence is greater than that found in earlier studies (17) but is comparable to recent studies that describe endocarditis in 20% to 25% of device-related infections (30,31). The incidence will vary according to the institution's referral characteristics, how device-related endocarditis is defined, as well as imaging modalities utilized. For the purpose of this study, we included patients with clinically definite or possible endocarditis by modified Duke criteria. The 16 patients who were classified as possible endocarditis had evidence

**Table 1** Patient Population

Patients, n	984
Leads extracted, n	1,838
Patients infected, n (% of all patients)	480 (49)
Infected leads, n (% of all leads)	1,000 (54)
Infected patients with vegetation, n	100
Percent of total patients	10
Percent of infected patients	21
Infected leads from patients with vegetation, n	215
Percent extracted leads	12
Percent infected leads	22

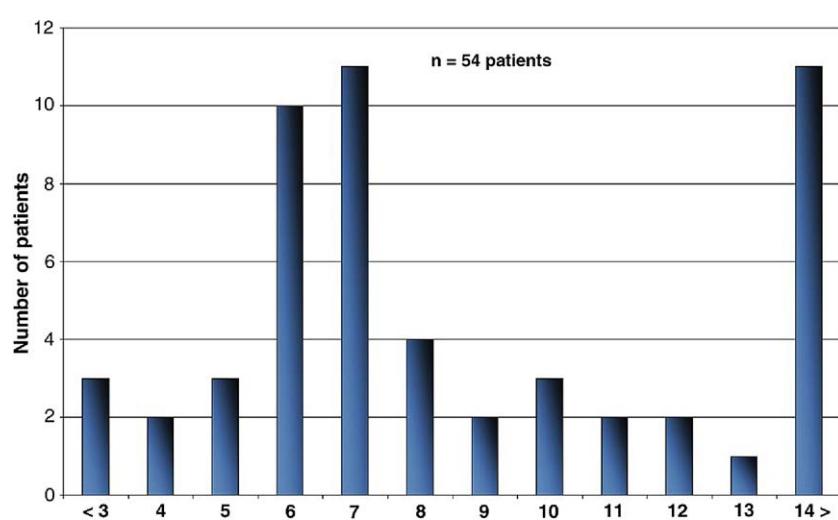


**Figure 3 Microbiology of Infected Devices**

Organisms isolated from blood cultures. "Others" include *Candida* species, *Citrobacter*, and *Streptococcus* species.

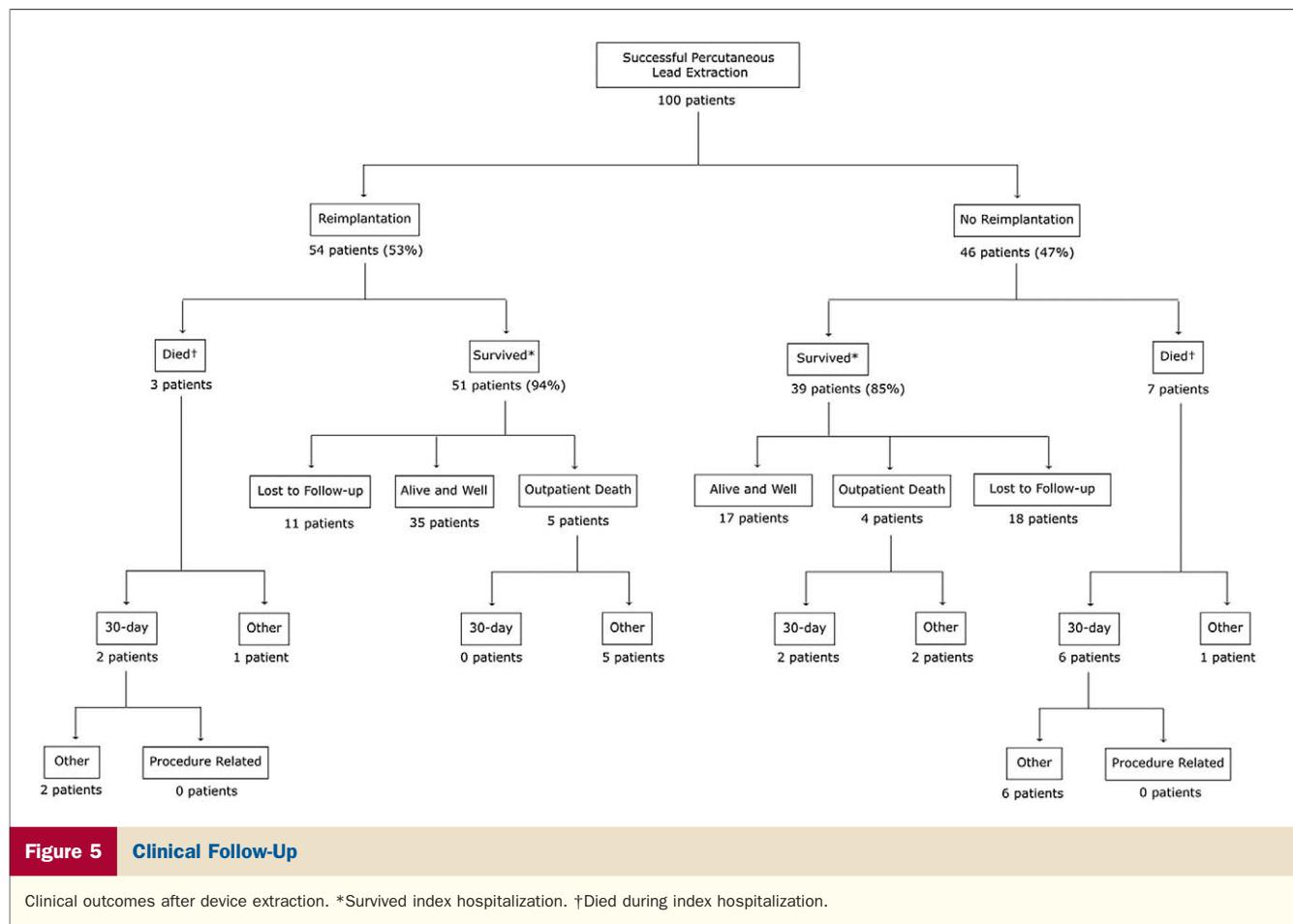
of vegetations but only clinically local infection with negative blood cultures. Without pathologic verification, these masses could represent fibrous casts or thrombus; however, the incidence of culture-negative endocarditis is ≈5% to 7%, and cultures preceded by antibiotics may be negative in as many as 14% of cases (32). Given the frequent ambiguity of initial culture data, we believe it is important to image all infected patients undergoing device extraction to identify high-risk patients and curtail future infection relapses.

**Feasibility.** All leads were successfully removed using a percutaneous approach. Implant duration and extraction time between the study group and the reference population were not significantly different. In fact, there was a trend toward shorter extraction times in patients with vegetations. This finding likely reflects improvement in extraction techniques and operator experience over time. Although we did not compare variables such as lead fixation mechanism or degree of fibrosis, our data suggest that the presence of intracardiac vegetations does not prolong extraction time.



**Figure 4 Reimplantation Time**

Number of days to reimplantation of a new device.



**Figure 5 Clinical Follow-Up**

Clinical outcomes after device extraction. \*Survived index hospitalization. †Died during index hospitalization.

Our data parallel the 93% to 97% percutaneous extraction success rates reported in other large cohorts (28,33–34). Smaller studies involving patients with endocarditis also document successful percutaneous extraction (14,15,30,35). Meier-Ewert et al. (30) successfully removed leads in 9 patients, and Victor et al. (15) removed leads in 9 of 12 patients; all vegetations were >1 cm. Massoure et al. (35) removed leads with a mean vegetation size of 1.3 cm in 36 of 37 patients.

One patient required a femoral approach using the Byrd workstation to snare a lead fragment that embolized to the pulmonary artery. Using the needle's eye snare or the Dotter Basket Retrieval System (Cook Vascular, Leechburg, Pennsylvania) in combination with countertraction is a well-described alternative (36–39). Published series from Klug et al. (36) and Espinosa et al. (38) have reported success rates of 87.2% and 82%, respectively.

Our data support the idea that a percutaneous lead extraction in patients with intracardiac vegetations has a high success rate and that leads can be removed in their entirety using standard techniques.

**Mortality and morbidity.** In our study the post-operative 30-day mortality was 10%. Although a standard measure of surgical outcomes, post-operative mortality may not reflect procedural mortality. The 10 patients who died had multiple comorbidities and overwhelming sepsis; their deterioration was secondary to the natural progression of disease.

One patient was transferred from an outside hospital on vasopressor support with septic shock. Although the device was extracted without incident, the patient died later that day after unsuccessful resuscitation. All other deaths occurred at least 5 days after extraction and were not a result of embolized vegetations or from the extraction procedure. These unfortunate outcomes occurred in a critically ill subset of patients who often have extensive comorbidities.

The overall mortality for percutaneous lead extraction reported from large databases or single centers with experienced operators is low. Mortality rates range from 0.1% to 0.6% and major complication rates range from 1.4% to 1.9% (20,27,33,34). Data regarding operative mortality for patients with intracardiac vegetations is less robust. Klug et al. (14) reported a mortality rate before discharge of 7.6% and an overall mortality of 26.9% at 20 months. Further, Victor et al. (15) reported deaths of 3 of 14 patients (21%) who underwent percutaneous lead extraction. Most recently, Sohail et al. (31) reported deaths of 9 of 189 patients (5%). Only 44 patients in that study had endocarditis; 5 of those patients died, yielding a mortality rate of 11%. All patients in our study had intracardiac vegetations. We believe that the 10% 30-day operative mortality rate in our series reflects severity of disease rather than the mode of extraction.

Depending on the definitions used, major complication rates reportedly range from 0.4% to 1.4% (33,34). Sohail et

**Table 2** Post-Operative 30-Day Mortality

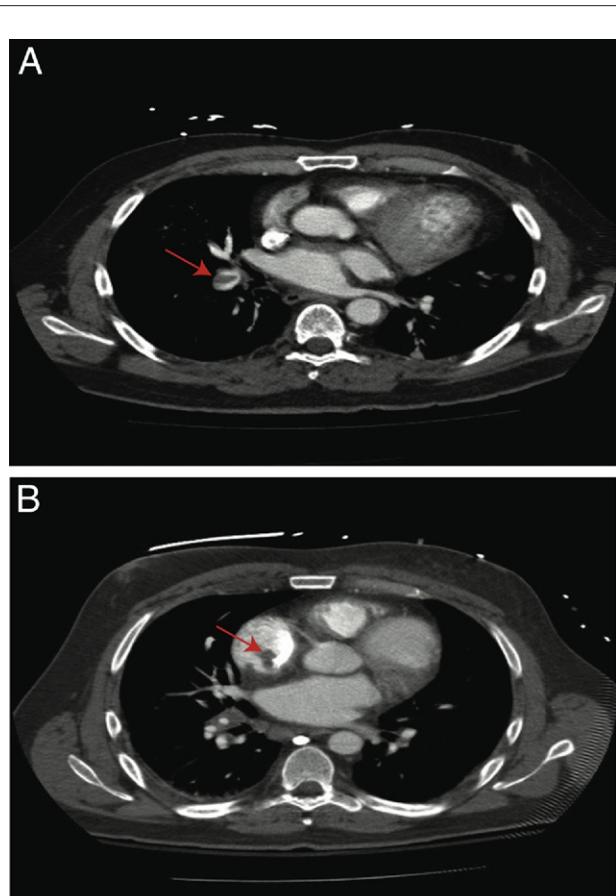
Patient #	Vegetation Size (cm)	Death After Explant (days)	Brief Clinical Summary
1	1.0	5	Device reimplanted but severe <i>Enterococcus</i> sepsis persisted with subsequent VDRF, ARF, and MOSF
2	2.9	21	Developed diffuse purulent lymphadenopathy and bilateral pneumonia; MSSA sepsis with septic emboli found at autopsy
3	NA	18	Fever, hypotension, and MRSA sepsis
4	NA	15	Treated for sepsis; post-extraction transesophageal echocardiogram revealed persistent mitral valve vegetation and right atrial mass. Transferred to skilled nursing facility 8 days later; died 1 week later of presumed septicemia
5	1.8	5	Initial device extraction without incident, new device reimplanted 4 days later; found unresponsive 1 day later; echocardiogram negative for tamponade; ACLS initiated for PEA code was unsuccessful
6	3.0	0	Transferred from outside facility on multiple pressors from septic arthritis that seeded device; was coagulopathic, which was reversed before extraction; worsening hypotension after procedure despite pressors; ACLS initiated but unsuccessful
7	2.2	14	MSSA sepsis with multiorgan failure; VDRF; ARF developed requiring HD; pseudomembranous colitis on multiple vasopressors; withdrawal of care
8	NA	12	Encephalopathic after procedure with hepatic failure; ARF requiring HD; hypotensive requiring multiple vasopressors; withdrawal of care
9	1.4	10	Had prosthetic valve endocarditis with perivalvular dehiscence; overwhelming sepsis developed with multiorgan failure, ARF requiring dialysis, atrial fibrillation, VDRF; withdrawal of care
10	1.5	20	Discharged from hospital with LifeVest; reportedly found unconscious at home and pronounced dead on arrival at hospital

ACLS = advanced cardiac life support; ARF = acute renal failure; HD = hemodialysis; MOSF = multiorgan system failure; MRSA = methicillin-resistant *Staphylococcus aureus*; MSSA = methicillin-sensitive *Staphylococcus aureus*; NA = not applicable; PEA = pulseless electrical activity; VDRF = ventilator-dependent respiratory failure.

al. (31) reported 20 patients (11%) who had complications after percutaneous extraction, but they are not categorized according to definitions published in previous guidelines. Limited data are available regarding complications during percutaneous lead extraction in patients with intracardiac vegetations. In our experience, 5 patients had complications related to the procedure, but none could be classified as major. We believe this is an acceptable complication rate given the high-risk nature of the population.

**Potential for pulmonary embolization.** A concern for septic embolization in patients with large vegetations >1 cm is documented in the literature (14,15,19,30). Studies involving right-sided endocarditis have documented an increased risk of embolization with larger vegetations but demonstrate an excellent prognosis and no detrimental impact on survival (35,40,41). Klug et al. (14) reported a pre-operative incidence of embolization, confirmed by ventilation-perfusion scans, in as many as 34% of patients. Meier-Ewert et al. (30) found evidence of pulmonary embolism in 5 of 9 patients (55%) by scintigraphic scans. Hospital stay for these patients was not statistically prolonged compared with patients without embolism.

In our experience, only 2 patients experienced witnessed embolization of vegetation material, which measured >2 cm before extraction in both cases. A third patient had presumptive embolization of a vegetation measuring 1.2 cm after extraction, and experienced transient hemodynamic changes requiring brief vasopressor support. All 3 patients made a full recovery and were discharged home. It is conceivable that septic embolization may have caused the

**Figure 6** High-Resolution CT Angiography

High-resolution computed tomography (CT) angiography indicates (A) a filling defect in the right middle pulmonary artery (red arrow), consistent with septic pulmonary embolism, and (B) a filling defect in the right atrium (red arrow) at the junction with the superior vena cava, consistent with retained vegetation.

death of 1 patient who died the day of extraction; however, her clinical deterioration prevented any confirmatory imaging, and she was overwhelmingly septic before the procedure. Routine imaging was not performed in this series, but given the aforementioned studies and the frequent absence of vegetations seen on post-operative imaging, the incidence of silent embolism is likely higher. Although embolization represents a potential complication and is likely underestimated in our experience, our data suggest that the majority of patients with vegetations up to 4 cm in size can safely undergo percutaneous lead extraction without clinical compromise.

**Method of extraction.** Historically, patients with intracardiac vegetations have preferably been managed by surgical approaches to directly visualize lead removal and limit the risk of lead fragmentation, tricuspid valve damage, and septic embolization that occurs with percutaneous techniques. In these situations, success with conventional median sternotomy with or without cardiopulmonary bypass as well as the limited atriotomy approach is well described (14,28,29,42,43). Unfortunately, there remains significant morbidity and mortality due to the invasive nature and prolonged recovery times, with mortality rates ranging from 12.5% to 40% (20,28,29). No study to date directly compares surgical and percutaneous approaches, and data are limited in patients with intracardiac vegetations. Table 3 compares mortality rates for both surgical and percutaneous techniques.

**Study limitations.** Our experience represents that of a tertiary care referral center. Results at centers without comparable experience with lead extraction may differ. Further, standard-

ization of post-operative care and long-term follow-up is limited as many patients were referred back to their primary institution. The true incidence of intracardiac vegetations may be overestimated because of our referral bias and the method used to define endocarditis. Although the modified Duke Criteria served as a guideline to define endocarditis, histologic confirmation was not performed, and thus thrombus and fibrous casts may have been mistaken for vegetation. Further, some echocardiograms were unavailable for review and thus represent a source of potential false positive vegetations. In addition, our use of TEE to screen patients with localized lead erosion discloses additional patients with intracardiac vegetations who may have been overlooked otherwise.

## Conclusions

As indications for device implantation expand, the prevalence of device-related infections will increase. Vigilant recognition and aggressive management should be the pillars of therapy if potentially fatal complications are to be avoided. Patients with infection and intracardiac vegetations represent a high-risk population with multiple comorbidities and significant mortality regardless of management strategy. Our experience suggests that percutaneous lead extraction, when performed by experienced operators, using standard techniques is both safe and feasible in patients with intracardiac vegetations up to 4 cm. Neither the causative microorganism nor the presence of intracardiac vegetations impacts the time required for lead extraction. Additionally, reimplantation of CRM devices is

**Table 3** Literature Review of Surgical and Percutaneous Lead Extraction Mortality

First Author, Year (Ref. #)	n	Extraction Approach*	Post-Operative Mortality, % (n)	Major Complications†	Comments
Brozman, 1992 (18)	11	Surgical	9% (1)	NA	Death related to sepsis
Frame, 1993 (10)	13	Surgical	15% (2)	NA	Deaths related to sepsis
Klug, 1996 (14)	12‡	Surgical	16.6% (2)	NA	Deaths related to sepsis; post-operative mortality 7.6%; 30% septic embolization
	38‡	Percutaneous			
Cacoub, 1998 (28)	29‡	Surgical	12.4% (4)	NA	Post-operative period defined as <8 days; IE proven by histology; overall mortality 24%
	4‡	Percutaneous			
Byrd, 1999 (33)	2,338	Percutaneous	0.4%	1.6%	U.S. lead extraction database
Victor, 1999 (15)	9‡	Surgical	11% (1)	NA	Deaths related to sepsis and heart failure; 12 patients had vegetations >1 cm
	14‡	Percutaneous	21% (3)		
Byrd, 2002 (44)	1,684	Percutaneous	0.8% (13)	1.9%	Total laser experience in U.S. (1995–99)
del Rio, 2003 (29)	5‡	Surgical	40% (2)	40%	12.5% “surgical” mortality includes surgical and percutaneous approaches
	25‡	Percutaneous	4% (1)	8%	
Meier-Ewert, 2003 (30)	9‡	Percutaneous	11% (1)	NA	Death from sepsis; 55% septic emboli
Massouire, 2007 (35)	20‡	Surgical	5.3% (3)	NA	90% with IE; mean vegetation size 1.3 cm; deaths related to sepsis
	37‡	Percutaneous			
Sohail, 2007 (31)	19	Surgical	5.3% (1)	26%	7 deaths during IH, only 2 procedure related; 5 deaths (11%) due to sepsis in 23% with IE
	166	Percutaneous	0.6% (1)	12%	
Camboni, 2008 (45)	21	Surgical	9.5% (2)	14%	Long-term survival between groups similar ( $p = 0.11$ )
	53	Percutaneous	0%	6%	
Jones, 2008 (34)	485	Percutaneous	0%	0.4%	Limited data on 85 patients with IE

\*Surgical extraction performed through median sternotomy or right atriotomy with or without cardiopulmonary bypass; percutaneous extraction performed using current standard techniques. †Major complications as published in prior guidelines (42). ‡Patients met criteria for definite or possible device-related endocarditis.

IE = infective endocarditis; IH = index hospitalization; NA = not applicable (study did not report surgical versus percutaneous mortality data).

feasible and safe when guided by standard principles of infectious disease. Prospective randomized trials are needed to determine appropriate methods of surveillance for vegetations and timing of device reimplantation so relapse of infection can be minimized.

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**Key Words:** percutaneous lead extraction ■ intravascular infection ■ endocarditis ■ vegetations ■ cardiac device infection ■ cardioverter-defibrillator ■ pacemaker