Prophylactic Lead Extraction at Implantable Cardioverter-Defibrillator Generator Change

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Background—Current implantable cardiac devices have a finite battery life of 3 to 7 years for implantable cardioverter-defibrillators. It is current practice to reuse all properly functioning intravascular leads. We tested the hypothesis that a strategy of prophylactic lead removal at the time of device change would be superior under some conditions to the current practice of lead reuse.

Methods and Results—Using currently available data and a Monte Carlo microsimulation trial, we calculated the risks of leaving an indwelling lead until extraction is indicated because of malfunction versus an aggressive management strategy of prophylactic serial extraction at time of generator change. With a serial lead exchange strategy of leads at generator change, there is reduced overall extraction-related mortality because of fewer late complications attributable to extraction of leads with high dwell time because of infection, recall, or subsequent lead failure. This finding is limited to young patients or those with high expected indwell time of lead. This trend reverses for leads with <40 years expected dwell time. Sensitivity analysis shows high dependence on extraction performance and device longevity. In all cases, serial extraction would be expected to lead to increased adverse events related to the more complex procedure.

Conclusions—A strategy of serial lead extraction, given best available current parameters, yields a lower procedural mortality risk in the long-term management of indwelling implantable cardioverter-defibrillator leads in young patients (>40-year estimated dwell time) driven by high aggregate anticipated risk of lifetime lead complication.

Key Words: defibrillators, implantable • lasers

Implanted cardioverter-defibrillator (ICD) leads have an expected useful lifetime that exceeds that of implanted devices and are routinely left in place if functioning well at time of generator changes secondary to battery depletion. However, long-term studies indicate that the failure of ICD leads is significant and the absolute risk increases with time, with estimates approaching 20% at 10 years of indwelling time per lead. Failures can be related to breach of insulation, conductor fracture, or the lead–myocardium interface manifesting as reduced sensing amplitudes or increased capture thresholds. In addition, many leads are ultimately found, through postimplantation follow-up, to have accelerated rates of failure, as recently seen in the St. Jude Riata lead family or Medtronic Fidelis models recalled by the United States Food and Drug Administration.

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ICD and pacemaker leads may be removed, which commonly occurs during lead failure or system infection. The difficulty in lead extraction is proportional to the indwelling time of the lead because of increasing fibrosis around areas of contact between the lead and surrounding vasculature and myocardium. Extraction success has increased with use of modern extraction techniques incorporating use of a laser-powered sheath that is able to be selectively applied to disrupt adherent tissue, compared with older traction-only or non-powered telescoping sheath–based methods.

Experience with lead extraction in recently implanted leads under recall advisory has shown that during the first few years after implantation, a low risk of major complication is present compared with the aggregate extraction risk of leads with longer dwell times.

Current ICDs have pulse generators that last 3 to 7 years. At the time of generator exchange, the patient is undergoing a surgical procedure and there is a fixed overhead of risk from anesthesia, infection, and related complications. Thus, it is attractive to consider a strategy of serial replacement of the functional ICD lead to prevent the formation of fibrosis and lead adherence resulting in future complications. The trade-off is between the risks of serial short dwell time lead extractions at each generator exchange against the high risk of a single extraction of leads with long dwell times.

There are significant data available regarding modern extraction risk and outcomes for leads of different ages. Using this data, combined with aggregate data of replacement outcomes with first generator change in a recalled lead, together with overall failure characteristics, we investigated in this study the trade-off between a serial lead exchange strategy at ICD generator change with lead reuse strategy with...
subsequent abandonment or late extraction using a microsimulation modeling technique.

A population of patients similar to overall demographic of patients receiving ICD, as represented by the Multicenter Automatic Defibrillator Implantation Trial II (MADIT-II) population, was used for initial modeling. Because younger patients in particular would expect to benefit from aggressive replacement strategies disproportionally, simulated cohorts of younger patients were specifically used as input with the lead management strategies outlined.

**Methods**

All simulation was performed using the MATLAB interpreted language (Mathworks, Inc., Natick, MA) and run in the open-source Linux version 3.2.7 64-bit operating system on an Intel Xeon server (IBM Corporation, Armonk, NY). No institutional review board approval was sought or required given the nature of this simulation study using virtual patients from published data sources.

**Virtual Patients**

Table 1 shows the tracked variables for each virtual patient. The simplified flowchart of the simulation algorithm is shown in Figure 1. Major increment was performed yearly. All probabilities were assessed in a reasonable clinical order: death by natural causes, followed by lead failure events, ICD elective replacement indicator events, with then modeling of appropriate action if necessary, guided by lead strategy. Periprocedural events were then modeled before next increment.

**Data Sources and Input**

In the event of nonannually observed data, data interpolation was performed using a constant fixed probability over desired iteration.

**Table 1. Significant Variables in Each Virtual Patient Tracked by the Program**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Initialized to age at start of simulation and incremented yearly.</td>
</tr>
<tr>
<td>Strategy</td>
<td>Remains constant during simulation, no crossover performed.</td>
</tr>
<tr>
<td>Serial replacement</td>
<td>Immediate extraction on failure</td>
</tr>
<tr>
<td>Add lead until extraction required</td>
<td>Unless otherwise noted, trial starts with insertion of new device.</td>
</tr>
<tr>
<td>Device age</td>
<td>1 for first device, increment each generator change or lead malfunction</td>
</tr>
<tr>
<td>Lead ages</td>
<td>Array of lead ages, ≤ 5 leads, if &gt; 5 leads required, extraction is performed.</td>
</tr>
<tr>
<td>Infection</td>
<td>Presence of infection, spontaneous or associated with generator change.</td>
</tr>
<tr>
<td>Death</td>
<td></td>
</tr>
<tr>
<td>End point</td>
<td></td>
</tr>
<tr>
<td>Extraction</td>
<td></td>
</tr>
<tr>
<td>Extraction death</td>
<td></td>
</tr>
<tr>
<td>Lead failure</td>
<td>Lead failure probability as a function of indwell time. May be fixed or accelerating risk, determined by known lead failure characteristics.</td>
</tr>
<tr>
<td>Lead failure–related death</td>
<td></td>
</tr>
<tr>
<td>Major adverse cardiovascular event</td>
<td></td>
</tr>
<tr>
<td>Natural death</td>
<td>Death probability depends on comorbidity and adjusted National Vital Statistics Reports rate as described.</td>
</tr>
</tbody>
</table>

**Overall Mortality**

Annual risk of mortality from natural causes was taken from the life table published by the United States Center for Disease Control National Vital Statistics Reports. For all patients, a factor of 1.2 was used to form the adjusted patient yearly probability of death, given patient population risk.

**Reuse and Replacement Strategy**

For all cohorts of patients, simulation was performed using 3 main strategies on reaching elective replacement indicator, event of infection, or failure of a lead. In all cohorts, infection led to removal of all indwelling leads with risk determined by dwell time of oldest lead, as detailed below, with implantation of new system if patient survives event.

**Serial Replacement**

Strategy 1 involved aggressive serial replacement, with removal of an always relatively fresh lead (generally <10-year indwell time) at elective replacement indicator and generator replacement, with the risks as outlined by the LExiCon data for extraction with all leads < 10-year indwell time. Lead failure led to replacement of lead system with new generator if current device was >2 years old, and infection resulted in extraction of all leads with placement of new generator.

**Extraction on Failure**

Strategy 2 involved waiting until a failure of any lead, followed by immediate extraction of the lead and replacement with a new lead, as opposed to adding another lead.

**Aggressive Reuse**

Strategy 3 was based on aggressive reuse of leads or nonextraction, with failure of a lead prompting addition of another lead, if no indwelling lead was ≤ 2 years old. If any implanted lead was relatively new (≤ 2 years old), then the most recent lead was extracted with corresponding low mortality and major adverse event (MAE) risk. If lead addition would result in > 5 leads total, or if infection is present, then removal of the system resulted.

In the case of noninfection failure, if a fresh lead (≤ 2 years) is present, a low-risk extraction of that fresh lead is assigned, given the likelihood of mobilization of a fresh lead without interaction with other leads. In the case of longer dwell times, or presence of infection, the risk is assigned to the cohort determined by the longest indwell lead.

**Device Longevity**

Longevity of ICD was estimated using recent data across manufacturers. Sensitivity analysis for this variable was performed by modeling increases in longevity as described. No projected increases in device longevity were modeled over time.

**Risk of Lead failure**

Aggregate risk of lead failure for ICD was modeled using data from Kleemann et al to adjust to a constant annual failure risk unless otherwise stated, extrapolated with fixed yearly 2% risk of failure during indwell time. Only ICD/right ventricular lead failure triggered immediate action in the study according to the strategy involved.

Lead extraction risk was dependent on lead age, and failure probability was cumulative with lead age as described. The total rate of MAE, death via natural or complication, and mean time of survival were performed for all starting age cohorts.

**Extraction Risks**

For leads ≤ 6 years old, data from the Multicenter Sprint Fidelis extraction were used to model extraction risk of mortality and MAE. For leads 6 to 10 years of age, aggregate data were used, and for leads > 10 years of indwelling time, extrapolation of LExiCon end
points for >10-year indwelling time lead subsets was conservatively estimated at 2% (LEXiCon aggregate, 1.86% mortality). The risks of mortality per extraction procedure were indexed to the oldest lead required to be extracted per strategy unless otherwise noted. Procedural risks did not compound if multiple leads were removed during each extraction, given the aggregate outcomes in published data. Sensitivity analysis was performed by variation of input parameters according to standard processes in simulation. Each simulation cohort was run 10 times with results given as ±SD as indicated. Boolean (binary) variables were given as count for each trial, with the SD of counts for all trials listed in summary statistics.

Results

MADIT-II Population

Using baseline best estimates of extraction and failure risks, the aggregate outcomes of MAE and extraction risk for the cohort of 10,000 patients with ICD aged 65±10 years with DEALE adjusted mortality of 1.2 are presented. This is similar to implant age of MADIT-II trial. Outcomes of the simulation are shown in Table 2. The MAEs are highest in serial

![Simulation Strategy Diagram](https://example.com/simulation_diagram.png)
replacement strategy in this population, and the most conservative management strategy of extraction only if required results in the lowest MAE and mortality.

Younger Cohort and Outcome by Age at ICD Insertion

With use of best available parameters, the initial age of the patient at the time of insertion of an ICD lead with plotting of the number of MAEs and mortality outcomes is shown in Figure 2. Error bars are from the SD of 10 separate simulations of 10,000 patients. As displayed in the figure, MAE outcomes are significantly higher in strategy 1 and 2, reflective of the relative high frequency of extraction of leads. Strategy 1 exhibits higher numbers of MAEs than strategy 2, because many of the extractions that are performed are ultimately clinically not beneficial because the patient would have a relatively short remaining lifespan, with correspondingly lower risk of actual lead failure. The number of lead failures is not significantly lower with increased aggression of extraction, which limits any benefit recuperated from the increased number of extractions performed.

Table 2. Summary of Baseline Simulation Results With Best Known Parameters, Run on 10,000 Patient Sample

<table>
<thead>
<tr>
<th>Strategy 1 (Serial Replacement)</th>
<th>Strategy 2 (Extract on Failure)</th>
<th>Strategy 3 (Extract Only if Required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial age</td>
<td>65±10</td>
<td>65±10</td>
</tr>
<tr>
<td>No. of devices</td>
<td>3.07±0.43</td>
<td>3.07±0.44</td>
</tr>
<tr>
<td>No. of infections</td>
<td>439±66</td>
<td>416±64</td>
</tr>
<tr>
<td>Lead failure</td>
<td>3306±27</td>
<td>3617±91</td>
</tr>
<tr>
<td>Age at end point</td>
<td>82.6±8.6</td>
<td>82.6±8.7</td>
</tr>
<tr>
<td>Major adverse events</td>
<td>257±13</td>
<td>168±14</td>
</tr>
<tr>
<td>Extraction-related death</td>
<td>27±6</td>
<td>47±7</td>
</tr>
</tbody>
</table>

Implant age approximates general implantable cardioverter-defibrillator population from MADIT-II (Multicenter Automatic Defibrillator Implantation Trial II) study, 65 years with SD 10, and is starting patient age in this model. Summed or counted results are averaged from individual trials, with SD listed from 10 separate simulation trials. Nondiscrete results (age at end point) include aggregate results from all trials.

Figure 2. Plot of expected major adverse event (A) and procedure-related mortality (B) per 10,000 patients as function of patient starting age and strategy used.
Variation of outcome based on lead indwell time is shown in Figure 3, with the MAE and mortality outcomes graphed from simulation in a cohort of patients implanted at 20 years of age. There are significantly higher MAEs seen with the serial replacement strategy (strategy 1) compared with extraction only if required (strategy 3), but the MAEs of serial replacement and extraction on failure (strategy 2) are both higher in value and similar in magnitude evidenced by overlapping error bars. At 40 years of lead indwell time, the expected mortality related to prophylactic extraction similar to that of a strategy that may result in late lead extraction, and serial replacement becomes, on average, an advantageous strategy with lower mortality past 45 years of indwell time.

**Effect of Device Longevity Increases**

To account for increasing device longevity, increase of the replacement interval is shown in Figure 4 for both extraction outcome and MAE. With longer intervals between extraction, the risks of a serial extraction again significantly increase, primarily driven by the observed higher risks in routine extraction of leads that are >10 years old. With this rapidly increasing risk of serial extraction with longer device longevity, retained lead strategies become most advantageous.

**Discussion**

These findings show that for established leads in patients of standard age ICDs, an optimal strategy to minimize overall MAEs is one of conservative lead management. Under this scenario, leads are reused unless accelerated failure is anticipated or infection is present.

However, this simulation supports that in younger patients, those aged <30 years, there is lower extraction-related mortality with a serial lead replacement strategy, driven by the cases in which lead or device complications are present long after insertion. In this scenario with later complications, the lead extraction risk of a potentially decades old lead significantly increases relative to having a recently inserted lead. However, given the elevated risk of MAEs overall for patients with a serial extraction strategy, the MAE risk is elevated with serial replacement.

Strategy 2, in which extraction is immediately performed on failure of a lead, is identical to one in which failure of a lead would by necessity require extraction, such as known vascular occlusion with contraindication to implantation on contralateral side, or presence of 5 leads through the superior vena cava, in which extraction is generally advised.

**Figure 3.** Major adverse event (MAE; A) and mortality (B) as a function of strategy by lead indwell duration on a simulated cohort of patients implanted at 20 years of age with indwell time as indicated. **B.** Comparison of the relative mortality of strategy 1 and 3 for various lead indwell times. See text for discussion.
As shown in Figure 4, increase in device lifetime rapidly eliminates any theoretical benefit from serial replacement because the risk of intervention approaches that of chronic leads at routine device change. Simply put, as battery life approaches 1 decade, the extraction risk is significant even with a serial replacement strategy and would overshadow any benefit from having a new lead. Given that ICD batteries are expected to last longer in the future because of higher charge density, unless negated by smaller size devices or increased circuitry drainage, over the years the interval between device changes would be expected to increase. With device longevity of >6 years and current risk estimates, there is no mortality benefit to a serial exchange strategy over the other competing strategies.

Limitations of Study
This study did not address the additional monetary cost of hardware associated with extraction, costs of maintaining surgical backup for the extraction procedure, and the additional costs of general anesthesia and overnight hospitalization associated with new lead implantations.

Nontangible Benefits and Risks
Serial lead replacement may lead to other benefits from having fresh lead, including the ability to deal with late accelerated failure or advisory leads with relative ease, in addition to access to updated technology such as alternate pacing site technology, or possible benefits of reduced lead diameter from more modern leads.

There are clear risks to any serial replacement strategy that are not entirely captured by this simulation. Although we take great care to model the risks of reimplantation with a new lead and the increased risks of dislodgement, infection risk, fluoroscopic, and procedure time, numerous unforeseen and difficult to model results may occur, such as an encountered subtotal occlusion now requiring unforeseen extraction or difficulty in placing a new lead on failure despite patent vasculature. Some have also theorized that endothelial disruption may take place with the process of extraction, leading to increased risk of subsequent occlusion, venous thrombosis, or difficulty in future extraction. Fibrosis tends to be more robust in younger patients, which may complicate extraction; however, surrounding structures also tend to have additional strength compared with tissue in the elderly.

Moreover, as referenced earlier in this article, the data that are the underpinning of this simulation study in the baseline case come from aggregate extraction outcomes at experienced tertiary and quaternary care centers. Although this is generally done in the presence of infection, lead dysfunction, or another strong indication for explantation and thus is likely to be a higher aggregate risk than a routine extraction, this has not been demonstrated and the true risks remain unknown.

In a serial replacement strategy, access to the vasculature is needed, which generally is a low-risk procedure. Although cephalic access carries extremely low risk of pneumothorax, it is doubtful whether this could be used more than once given the often destruction of the vessel, so an axillary or subclavian approach would be used for replacement. In addition, these risks from vascular access may be minimized via using needleless access techniques if the lead is freely mobile in the circulation and may be also accomplished via the laser sheath access site, reducing risks inherent to de novo vascular access.

For pacemaker-dependent patients, it is unlikely that serial exchange would be a favorable strategy because of the risk of dislodgment being higher in the recent postimplant period, and the development of fibrosis with favorable lead parameters aids in the reliability and security of the lead. Any failure related to fresh lead implant is possibly catastrophic and would be estimated to be higher than the cumulative benefit from serial exchange.

Finally, it should be noted that an adverse outcome in the absence of a compelling individual indication for a procedure may be viewed as more tragic, even if there is a small overall statistical benefit to this action in the group. Primum non nocere has been a longstanding principle fundamental
to medicine. Furthermore, extraction-related mortality when required because of lead dysfunction in our simulation tends to occur in older individuals, whereas serial replacement-related mortality is evenly distributed throughout the lifetime. Possibly unnecessary death for a potential benefit in a younger individual would be tragic.

Conclusions
A serial lead extraction strategy in young patients may be expected to lead to lower aggregate extraction-related mortality under current lead failure conditions and extraction performance at the expense of significantly increased MAEs related to the more complex procedure of extraction compared with routine generator change. This trend depends on robust maintenance of low complication rates with routine extraction. Although this analysis and results lend support to the concept of serial lead extraction as a strategy with lower mortality outcomes, it does not definitively dictate widespread use or primary implementation. Second, it is of critical importance to remember that the patient, once falling into one of these strategies, is not locked into that strategy for life, and an early serial replacement strategy should be discontinued once the patient does not fit the criteria for its continued use, namely, as he or she ages and expected lead dwell time becomes shorter or if the interval between generator changes has increased because of improved ICD battery longevity over time.

Finally, it is essential that an operator knows his or her own results and expertise when performing these operations because experience has been shown to alter outcomes especially when extraction techniques are required. All of the risks evaluated in this article are low, so there will not be immediate feedback if a suboptimal strategy is used; patients will generally do well regardless of strategy chosen. Similarly, a relatively high individual complication rate from any aspect of the procedure, either implant or extraction, will significantly alter the trade-off modeled above, between serial exchange and lead retention. It is imperative to actively monitor personal and institutional performance to assure continuing assumptions regarding complication rates from procedures remain valid.

Disclosures
Dr Saba has received research support and consultation from Medtronic, Inc., Boston Scientific Inc., and St. Jude Medical, Inc. The other author reports no conflicts.

References

CLINICAL PERSPECTIVE
It is current practice to reuse implantable cardioverter-defibrillator leads at time of routine generator change. However, it is known that the longer these leads remain in the vasculature, the more difficult the leads are to extract if it becomes necessary. These risks of extraction have been quantified in recent years, confirming the relative difficulty in extraction of longer-term chronic leads, particularly those with indwell time >10 years. In this article, we demonstrate that young patients would be expected to have lower procedure-related mortality with a strategy of serial lead exchange, where new leads are placed at routine device change. This result is attributable to the expected long lead indwell time and high expected lifetime complication in these individuals.
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