



Reimplantation and long-term mortality after transvenous lead extraction in a high-risk, single-center cohort

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Abstract

Purpose The use of cardiac implantable electronic devices (CIEDs) has increased significantly over the last decades. With the development of transvenous lead extraction (TLE), procedural success rates also improved; however, data regarding long-term outcomes are still limited. The aim of our study was to analyze the outcomes after TLE, including reimplantation data, all-cause and cause-specific mortality.

Methods Data from consecutive patients undergoing TLE in our institution between 2012 and 2020 were retrospectively analyzed. Periprocedural, 30-day, long-term, and cause-specific mortalities were calculated. We examined the original and the revised CIED indications and survival rate of patients with or without reimplantation.

Results A total of 150 patients (age 66 ± 14 years) with 308 leads (dwelling time 7.8 ± 6.3 years) underwent TLE due to pocket infection ($n = 105$, 70%), endocarditis ($n = 35$, 23%), or non-infectious indications ($n = 10$, 7%). All-cause mortality data were available for all patients, detailed reimplantation data in 98 cases. Procedural death rate was 2% ($n = 3$), 30-day mortality rate 2.6% ($n = 4$). During the 3.5 ± 2.4 years of follow-up, 44 patients died. Arrhythmia, as the direct cause of death, was absent. Cardiovascular cause was responsible for mortality in 25%. There was no significant survival difference between groups with or without reimplantation ($p = 0.136$).

Conclusions Despite the high number of pocket and systemic infection and long dwelling times in our cohort, the short- and long-term mortality after TLE proved to be favorable. Moreover, survival without a new device was not worse compared to patients who underwent a reimplantation procedure. Our study underlines the importance of individual reassessment of the original CIED indication, to avoid unnecessary reimplantation.

Keywords Lead extraction · Pacemaker · ICD · CRT · Cardiac implantable electronic devices · CIED · Reimplantation · Mortality · Long-term follow-up · Cause of death

1 Introduction

The number of cardiovascular implantable electronic devices (CIEDs) has increased progressively over the past decades due to increasing life expectancy, wider scale of indications, guideline developments, and their favorable effect on morbidity and mortality in patients with heart rhythm disorders and cardiac

failure [1–4]. With the increasing use of CIEDs, an increase in demand for transvenous lead extraction (TLE) can be parallelly observed. Although leadless devices conquer ever broader territories, in transvenous CIEDs the lead remains the weakest link and lead management for infection or malfunction may be associated with adverse outcomes in the long run.

CIED leads undergo fibrotic encapsulation over time, whose mechanism is not entirely understood but is most likely due to simultaneous activation of cellular and humoral mechanisms [5]. TLE employs several methods in order to liberate targeted leads from fibrotic tissue, which binds them to major veins, cardiac structures, or other CIED leads [6, 7]. During the last decade, modern extraction tools and technical advancements improved the success rate and safety of the procedure, but TLE is still considered a high-risk intervention with serious potential complications and even death [8]. One

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of the biggest multicenter TLE databases demonstrated that procedure-related major complications, including death, can occur in up to 1.7% of the procedures [9]. Especially, cases with infected CIED system and longer dwelling time could be very challenging, requiring a multidisciplinary diagnostic and therapeutic approach [10]. Patients after previous device infection are thought to have higher overall risk in general and also greater chance for reinfections. Consequently, reassessment of the initial CIED indication after TLE is of paramount importance in order to avoid unnecessary implantations and concomitant risks.

Optimal timing of the reimplantation and its mortality effect, and impact of comorbidities, as well as data regarding long-term clinical outcomes of patients undergoing TLE, are still under active investigation [11–16].

The aim of our study was to analyze the long-term clinical outcomes after TLE, including reimplantation data, all-cause and cause-specific mortality.

2 Methods

2.1 Patient population

Clinical data were retrospectively collected from consecutive patients undergoing TLE between 2012 and 2020 at the University of Szeged.

Patients' demographics, echocardiographic data, device and lead parameters, primary indication of implantation, indication and details of the extraction procedure were collected at baseline. According to present guidelines [17–19], indications of the TLE were classified as pocket infection (i.e., local signs of inflammation, including pocket abscess, device erosion, skin adherence, erythema, warmth, fluctuance or chronic draining sinus without involvement of the transvenous portion of the lead system), endocarditis (with or without pocket infection, with positive blood cultures and lead or valvular vegetations), and non-infectious (redundant, abandoned or dysfunctional lead, lead-related complications, such as arrhythmias, thrombosis, perforation, chronic pain, or venous obstruction). Positive bacteriological analyses of lead fragments without macroscopic lead endocarditis on TEE, positive blood culture test, or clinical signs of systemic infection (fever, shivering, relevant elevation of inflammatory laboratory parameters) were considered pocket infection, since the contamination of the lead could have happened during the extraction of the lead through the infected pocket.

2.2 Lead extraction techniques

For TLE, a stepwise approach was used. Initially, the active fixation screw was retrieved (if available) and a gentle direct manual traction was performed using a conventional stylet. If

this was not successful, a locking stylet (Lead Locking Device, LLD, Spectranetics/Philips; Liberator, Cook Medical) was inserted and moderate traction was repeated. As the next step, laser (Glide Light laser sheath, Spectranetics/Philips) or mechanical (TightRail, Spectranetics/Philips; Evolution, Cook Medical) powered extraction sheaths were used at the discretion of the operators. If the superior approach was unsuccessful, the snaring technique was utilized, predominantly via femoral access in a relatively early phase.

TLE procedures were performed either in deep sedation or in general anesthesia, mainly in the EP lab, except the very high-risk extractions (i.e., previous extraction attempt resulting in highly disintegrated lead, dwelling time > 10 years for ICD leads and > 15 years for pacemaker leads) that were carried out in the operating room. A complete surgical team with a heart-lung machine and a surgical set for an emergency sternotomy was always available on standby. All the extractions were performed under fluoroscopic and intracardiac echocardiography guidance.

2.3 Study endpoints

Patient follow-up and survival data were obtained from the local and referral institutional medical records, family practitioners, and patients. Regarding long-term mortality, a complete dataset could be achieved by using the database of the National Health Insurance Fund of Hungary.

Procedural outcomes were defined in accordance with the 2018 EHRA expert consensus statement on lead extraction [17]. Complications were classified as intra-procedural, if related to the performance of a procedure that occurs or becomes evident from the time when the patient enters the operating room until the patient leaves the operating room. All-cause and cause-specific mortalities were calculated during the hospitalization period, within the first 30 days and during long-term follow-up. Assessment of cause-specific mortality was performed based on the Hinkle and Thaler classification, and determined as to be arrhythmia-related, cardiovascular, and non-cardiovascular causes [20].

If the revised indication suggested a need for a new CIED, reimplantation data were also analyzed. Reimplantations were either performed at our center or at the referral institute. A procedure was defined as an upgrade if the new device possessed more functions/leads (i.e., atrial pacing, resynchronization, defibrillator function), and downgrade if it possessed less functions/leads. There were patients who received a device with the same functions as previously. Survival rate between patients undergoing a reimplantation was compared to that of those without a new device.

The study was approved by the institutional review board of the University of Szeged and complies with the ethical guidelines of the Declaration of Helsinki.

2.4 Statistical analysis

Statistical analyses and survival plots were performed using SPSS Version 23.0.0 (Statistical Package for Social Sciences Inc.). Continuous variables were expressed as mean \pm standard deviation. Categorical data were expressed as frequencies and percentages. Survival curves were constructed using the Kaplan-Meier method and compared using the log-rank test. Two-sided p -values < 0.05 were considered statistically significant.

Risk factors for extraction failure were assessed by univariate and multivariate logistic regression models. To assess the survival effect of indication for extraction (i.e., pocket infection vs. endocarditis vs. non-infectious) or reimplantation, the Cox proportional hazards regression model was used. The statistical models were adjusted for typical risk factors and potential baseline confounders including sex, age, type of the extracted lead and dwelling time, indication of the extraction, major complication, procedural failure, previous box exchange, hypertension, cardiomyopathies, ischemic heart diseases, atrial fibrillation, diabetes mellitus, obesity, heart failure, hyperlipidemia, chronic obstructive pulmonary disease, chronic kidney diseases, stroke/TIA, left ventricular ejection fraction (LVEF), C-reactive protein (CRP), and procalcitonin (PCT), respectively. Parameters that tested $p < 0.10$ on univariate analysis were included into the multivariate models.

3 Results

3.1 Patient population

Between 2012 and the August of 2020, 150 patients underwent TLE procedure and a total of 307 leads were extracted. The mean age of the patients was 66 (± 14) years, of whom 76% ($n = 114$) were male. Comorbidities, population characteristics, and the primary indications for CIED implantation are presented in Table 1 and Fig. 1.

The average dwelling time of the leads was 7.8 \pm 6.3 years (median = 7, IQR 3–11). The oldest leads ($n = 4$) had been implanted for 30 years. Fifty percent ($n = 154$) of the leads were pacemaker, 34% ($n = 105$) coronary sinus, and 16% ($n = 48$) ICD leads, respectively, of which 69.7% had passive fixation. Dwelling time was longer than 10 years in 43% of the pacemaker leads and longer than 5 years in 53% of the ICD leads, as shown in Fig. 2. The number of leads extracted per procedure was 2 \pm 1.

The indications for lead extraction were infectious (93%, $n = 140$) and non-infectious (7%, $n = 10$). Infectious indications were dichotomized into pocket infection (70%, $n = 105$) and endocarditis (23%, $n = 35$), as defined in the “Methods” section.

Table 1 Baseline characteristics of all patients

$n = 150$			
Sex (male)	114 (76%)		
Age	66 \pm 14 years		
Lead dwelling time	7.8 \pm 6.3 years		
Type of the extracted leads			
Pacemaker	154 (50.2%)		
Coronary sinus	105 (4.2%)		
ICD	48 (15.6%)		
Comorbidities			
Hypertension	119 (79.3%)		
Heart failure	81 (54%)		
Cardiomyopathies	61 (40.7%)		
Dilated CM	32		
Ischemic CM	25		
Hypertrophic CM	4		
Ischemic heart diseases	55 (36.7%)		
Atrial fibrillation	53 (35.3%)		
Diabetes Mellitus	35 (26.7%)		
Obesity	35 (23.3%)		
Hyperlipidemia	30 (20%)		
COPD	17 (11.3%)		
Chronic kidney disease	15 (10%)		
Stroke/TIA	14 (9.3%)		
DVT	10 (6.7%)		
PAD	9 (6%)		
Laboratory parameters			
EF (%)	51 \pm 17		
Se creatinine (μ mol/l) [£]	100.4 \pm 49		
CRP (mg/l)*	< 2	2–50	50 <
	29	95	11
PCT (ng/ml) [€]	< 0.06	> 0.06	
	52	32	

[£] Available for 142 pts

*Available for 135 pts

[€] Available for 84 pts

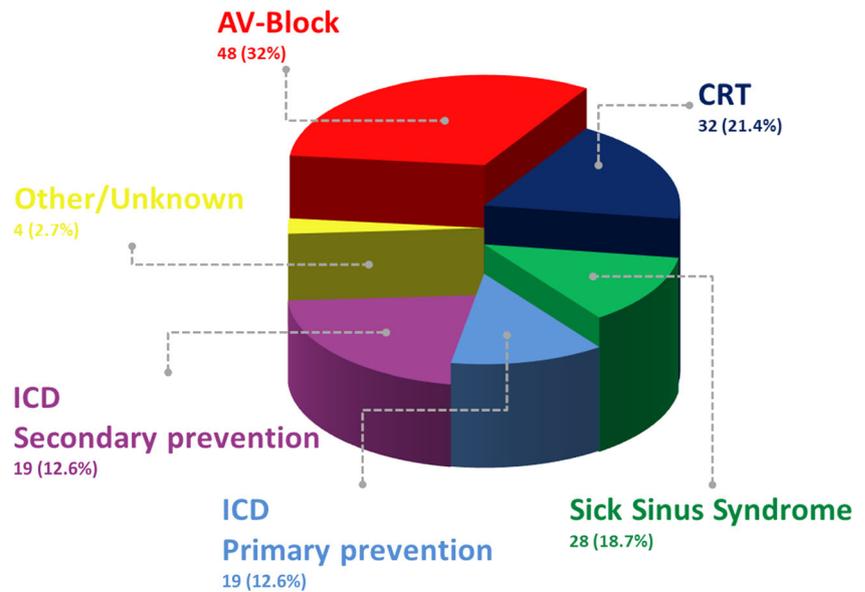
COPD chronic obstructive pulmonary disease, DVT deep vein thrombosis, PAD peripheral artery disease, EF ejection fraction, CRP C-reactive protein, PCT procalcitonin

3.2 Procedural outcomes

Locking stylet was used in 81.1% of the cases. In 73% of the procedures, active extraction sheaths, such as laser (56%) and/or mechanical rotating dilator (28.5%), were used. Snare technique from femoral or jugular approach was necessary in 25.3% of the cases.

Complete procedural success was primarily achieved in 87% of the cases. In another 6% of patients, residual leads

Fig. 1 Primary indication of CIED implantation



were successfully extracted during elective sternotomy. Minor complications (i.e., formation of hematomas) occurred in 9.3% ($n = 14$). There were 5 major complications (4 vena cava superior injuries, 1 cardiac perforation at the level of the right atrium) requiring rescue sternotomy. All five cases had pacemaker leads, the primary CIED indication was sick sinus syndrome, and the indication for TLE was any form of infection (2 systemic and 3 pocket infections). Death occurred despite urgent pericardiocentesis and heart surgery in 3 patients (2%). It is important to mention that all 3 patients, who died during the procedure had a previously failed extraction attempt at referral institutions. Their passive fixation pacemaker leads were 19, 8, and 6 years old (Fig. 3).

There was 1 death during the 30-day follow-up. A 72-year-old female patient with pocket infection died during the post-operative treatment in the intensive care unit due to overwhelming sepsis. Univariate and multivariate logistic regression was performed to identify factors that may influence procedural success. The results are shown in Table 2. After

multivariate analysis lead dwelling time (OR 1.24, 95%CI 1.16–1.33, $p < 0.001$), infectious indication (OR 12.12, 95%CI 2.9–50.63, $p = 0.001$), and atrial fibrillation (OR 8.44, 95%CI 1.87–38.01, $p = 0.005$) remained statistically significant.

3.3 Reimplantation data

After TLE, CIED indication was reassessed and compared with the original indications of implantation (Fig. 1). If the risk/benefit ratio supported a reimplantation, a new device was implanted, in 26% following temporary pacing.

Seventy-six percent of the patients underwent a reimplantation: 59% received a device with the same functions, in 13% a downgrade, and in 4.1% an upgrade procedure was performed. The average time interval between extraction and reimplantation was 64 days, ranging from 0 days (same day) to 2.3 years. In 24% of the patients, no new device was implanted at all, 20 of them had previously a pacemaker, and 4 of

Fig. 2 Dwelling time of the extracted leads

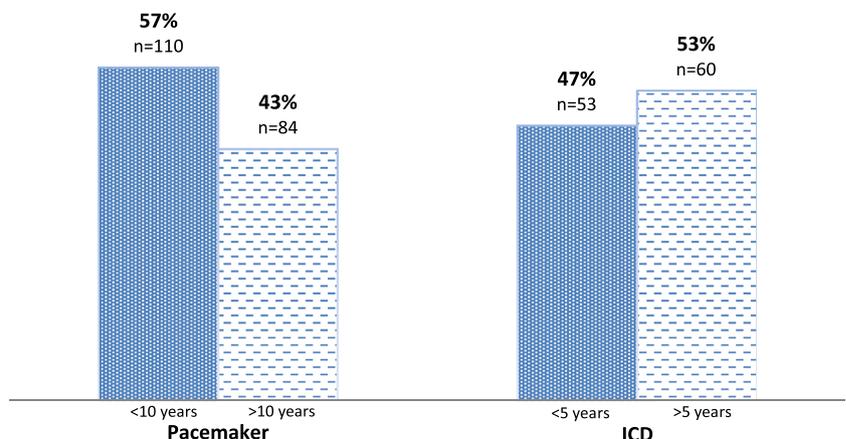




Fig. 3 Preoperative chest X-ray of a 74-year-old male having two, 8-year-old, passive fixation, truncated, and highly disintegrated leads beside his new VVI pacemaker system implanted from the right side

them an ICD device (3 with primary and 1 with secondary prevention).

3.4 Long-term mortality

The mean follow-up time was 3.5 ± 2.4 years. Follow-up data regarding all-cause mortality was complete for all patients. During this period, 44 of 150 patients died. The cumulative mortality was 4.7% at 6 months, 8% at 1 year, and 24.7% at 5 years (29.3% total mortality). Survival charts of patients with different indications for TLE are shown in Fig. 4. There was no statistically significant difference in the risk of mortality in any comparison of the 3 groups (i.e., pocket infection vs. endocarditis vs. non-infectious, all $p = n.s.$); however, patients with infection tend to have a poorer survival (HR 4.5, 95%CI 0.62–32.71). Comparison of baseline characteristics of these subgroups is shown in Supplementary Table 1.

Cause-specific mortality was available in 30 cases, as detailed in Table 3. There was no death related to arrhythmia. Cardiovascular cause was responsible for death in 25% (heart

failure $n = 9$, stroke $n = 1$, myocardial infarction $n = 1$), and non-cardiovascular causes in 36%.

The analysis did not identify significant differences in long-term survival between patients with or without reimplantation ($p = 0.141$) (Fig. 5, Supplementary Table 2). Notably, there was no death associated with cardiac cause in the non-reimplant group.

4 Discussion

4.1 Main findings

TLE is the gold standard therapy for treating CIED-related infections and for non-infectious lead-related complications. The results of our retrospective single-center analysis confirm that both short- and long-term outcomes of the procedure are favorable even in a very high-risk population. Furthermore, our study underlines the importance and safety of the critical revision of initial CIED indication after extraction, to avoid unnecessary reimplantations.

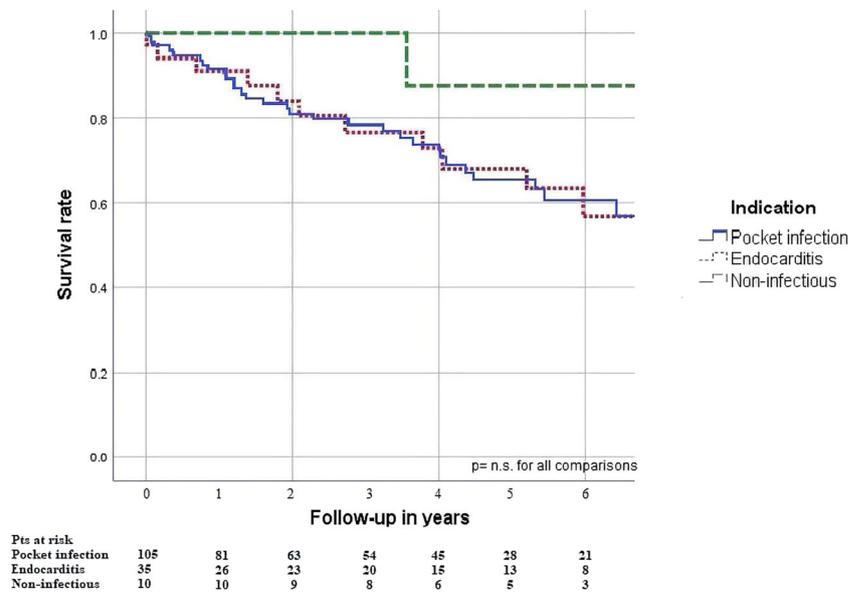
4.2 Procedural outcomes and risk factors

In the current study, TLE was performed in a cohort with a 93% infectious indication rate, which is one of the highest ratios published in the literature. In-hospital mortality rate was 2.6%, which is slightly higher, than the one observed in the biggest international TLE registry (i.e., 1.4%); however, infectious indications were responsible only for 53% of the cases in that database [9]. In general, it is well accepted that CIED infection is one of the most important risk factors upon survival [13, 14, 16]. Milman et al. [21] and Maytin et al. [22] published similar findings regarding short-term mortality; procedural death occurred only in the infectious groups in their studies. Our analysis did not find significant correlation between short- or long-term survival and the indication of the procedure; however, this can be explained by the underrepresentation of the non-infectious group and relatively few endpoints (4 in-hospital deaths). Besides the difference between the infectious rates, it is also important to mention that 3 out of the patients with serious intra-procedural complications in our cohort had a previous extraction attempt at referral hospitals.

Table 2 Independent risk factors for extraction failure

Risk factor	Univariate analysis			Multivariate analysis		
	Exp (B)	CI	<i>p</i>	Exp (B)	CI	<i>p</i>
Lead dwelling time	1.2	1.13–1.27	< 0.001	1.24	1.16–1.33	<0.001
Infectious indication	4.08	1.2–13.91	0.025	12.12	2.9–50.63	0.001
Atrial fibrillation	5.47	1.6–18.27	0.006	8.44	1.87–38.01	0.005

Fig. 4 Indication of the extraction procedures and long-term survival



As one of the main extraction centers in Hungary, high-risk patients after unsuccessful extraction attempts are often admitted to our institute. Moreover, the mean dwelling time was also longer in our population compared to the one observed in the ELECTRa registry (7.8 ± 6.3 years vs. 6.4 ± 5.4 years) [9]. As shown in Fig. 2, a high proportion of the extracted leads had a prolonged dwelling time, which poses a serious risk regarding extraction.

Upon multivariate analysis, lead dwelling time, infectious indication, and atrial fibrillation proved to be independent risk factors for extraction failure (Table 3). The first two are well-known risk factors [16, 23]. Atrial fibrillation can probably be considered a general marker of cardiovascular fragility. There were more factors which were not significant alone in the multivariate analysis (hypertension, cardiomyopathy, diabetes mellitus, etc.), but are well-known predictors of atrial

fibrillation, which remained an independent predictor, giving a good overall reflection of one’s cardiovascular disease burden.

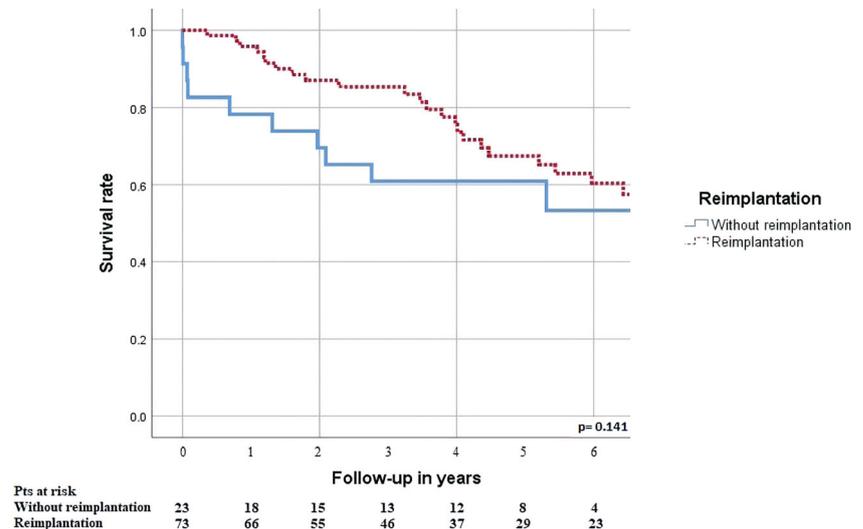
4.3 Reimplantation data

After the extraction procedure, the initial CIED indication was reassessed very carefully. If the patient presented CIED dependence, a new device was reimplanted. In 23.5% of the patients, no new device was implanted due to questionable initial indication and because individual risk/benefit ratio evaluation did not support the pertinence of reimplantation. Safety of this conservative strategy was confirmed by our results: cardiac-related deaths did not occur in the non-reimplanted group and there was no significant difference in long-term all-cause mortality between the two groups.

This strategy was also considered favorable in previous studies. Gomes et al. [13] reported a similar mortality in reimplanted and non-reimplanted patients (24% vs. 27%). In their study, 8% of the patients did not receive a new device after TLE procedure; bradycardia and sudden cardiac death were absent in this group. Al-Hijji et al. reported a lower survival rate in the non-reimplanted group (14% of study population), but death was not associated with cardiac cause or lack of CIED in 74% of the cases. [11] In a study by Döring et al., 37% of the patients did not receive CIED therapy after extraction, another 22% received a different device, and only 41% received the same device [12]. After adjustment for the type of infection, there was no significant difference in survival. Diemberger et al. [15] reported the most conservative approach. In their study, 54% of the patients formed the non-reimplanted group. During the mean follow-up of 3.8 ± 0.2

Table 3 Cause-specific mortality

Procedure related	3 (6.8%)
Cardiovascular	11 (25%)
Heart failure	9
Stroke	1
Myocardial infarction	1
Non-cardiovascular	16 (36.36%)
Malignancy	8
Sepsis	5
Dementia	2
Respiratory failure	1
Arrhythmia	0
Unknown	14 (31.8%)
Total	44 (100%)

Fig. 5 Reimplantation and long-term survival

years, survival of these patients was remarkably good with 16.5% of all-cause mortality.

We found no significant correlation between the timing of reimplantation and survival. The question of timing is still seeking for answers, especially in infectious cases. Few studies examined precisely its effect upon long-term outcomes and the available data are controversial and not really consistent. However, this disagreement can be the result of the simple fact that individual cases are by definition individual, not to mention that TLE candidates usually have numerous comorbidities, which further complicates our equation. Well-designed studies are needed to investigate factors that can be reliable markers to predict reinfection, lead remnant interactions, and surgical load.

CIEDs are becoming more widely available, which promotes the increasing possibility of overtreatment; thus, thorough evaluation of CIED necessity is crucial before reimplantation. One has to also consider that patients' cardiac condition and guidelines regarding implantation are changing over time. An appropriate therapy plan can be set up only by taking into account these dynamic parameters.

4.4 Long-term mortality

In 68% of the cases, cause-specific mortality was also available in our study compared to several TLE publications that are missing this feature. It is remarkable that only one-third of the deaths were cardiac related, and not a single one to arrhythmia. The most common non-cardiac causes were malignancy (45%), sepsis (17%), and dementia (11%). These results confirm that, despite high-risk conditions, TLE is a useful treatment which can improve patients' life expectancy and quality measures.

Our findings regarding long-term survival are similar with the findings of Gomes et al. who published a 33%

overall mortality rate with 65% infectious indication. Other studies showed a better long-term survival, but with higher percentage of non-infectious indications. Deckx et al. reported a 16.5% overall mortality rate with 17% infectious indication [16], and in a study by Merchant et al. long-term mortality reached 18.5% with a 32.5% infectious rate [14], while Maytin et al. reported a 26.6% mortality rate with 50% infectious indication [22]. In summary, the increase in infectious indication entails the increase in long-term mortality in different studies. Taking the 93% infectious indication rate into consideration, our long-term mortality results seem to be clearly favorable.

4.5 Limitations

Our study has all the limitations of retrospective analyses. Data regarding cause-specific mortality was only available in 68% of the patients, and reimplantation data in 98 cases. Accordingly, as a single-center study with a small cohort, our findings have to be evaluated with caution. Another limitation is that the non-infectious group was clearly underpowered; thus, long-term mortality data in this case may be non-representative.

5 Conclusions

Despite the very high percentage of pocket and system infections and the long dwelling times, the short- and long-term mortality after TLE proved to be favorable in our cohort. Moreover, survival without a new device was not worse compared to patients who had undergone a reimplantation. Our study underlines the importance of the individual

reassessment of the original CIED indication, in order to avoid unnecessary reimplantation.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10840-021-00974-4>.

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Author contributions This study was designed and coordinated by A.M., G.K., A.B., L.S., and M.V. The database was designed mainly by G.K. and supplemented by M.V. Data acquisition was performed by E.J.ZS., M.M., A.V., A.B., N.S., G.K., Z.H., G.B., and M.V. Statistical analysis and interpretation of the results were carried out by E.J.ZS., M.M., A.V., A.B., L.S., and M.V. The manuscript was drafted by E.J.ZS., M.M., L.S., and M.V. and was critically revised by all the authors. E.J.ZS. and M.M. contributed equally to this work as first authors. All the authors read and confirmed the final manuscript and agreed to be accountable for all aspects of the work.

Data availability Clinical data were retrospectively collected from consecutive patients undergoing TLE between 2012 and 2020 at the University of Szeged.

Code availability Not applicable

Declarations

Ethics approval The study was approved by the institutional review board of the University of Szeged and complies with the ethical guidelines of the Declaration of Helsinki.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest M.V. reports consulting fees and/or nonfinancial support from Abbott, Biotronik, Minimal Invasive Technology Ltd., and Sanofi-Aventis, outside the submitted work.

The other authors declare no conflict of interest.

References

- Bradshaw PJ, Stobie P, Knuiman MW, Briffa TG, Hobbs MST. Trends in the incidence and prevalence of cardiac pacemaker insertions in an ageing population. *Open Hear*. 2014;1.
- Brignole M, Auricchio A, Baron-Esquivias G, Bordachar P, Boriani G, Breithardt OA, et al. 213 ESC guidelines on cardiac pacing and cardiac resynchronization therapy. *Eur Heart J*. 2013;34:2281–329.
- Priori SG, Blomström-Lundqvist C, Mazzanti A, Blom N, Borggrefe M, Camm J, et al. 2015 ESC guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: the Task Force for the Management of Patients with Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death of the European Association of Cardiovascular Imaging and the European Heart Rhythm Association. *Europace*. 2015;17:1601–87.
- Ponikowski P, et al. ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J*. 2016;37:2129–2200m.
- Esposito M, Kennergren C, Holmström N, Nilsson S, Eckerdal J, Thomsen P. Morphologic and immunohistochemical observations of tissues surrounding retrieved transvenous pacemaker leads. *J Biomed Mater Res*. 2002;63:548–58.
- Perez AA, Woo FW, Tsang DC, Carrillo RG. Transvenous lead extractions: current approaches and future trends. *Arrhythmia Electrophysiol Rev*. 2018;7:210–7.
- El-Chami MF, Merchant FM. Femoral extraction of transvenous leads and leadless pacemakers—a review of the data, tools, and procedural steps. *PACE - Pacing Clin Electrophysiol*. 2019;42:1248–52.
- Monsefi N, Waraich HS, Vamos M, Erath J, Sirat S, Moritz A, et al. Efficacy and safety of transvenous lead extraction in 108 consecutive patients: a single-centre experience. *Interact Cardiovasc Thorac Surg*. 2019;28:704–8.
- Bongiorni MG, Kennergren C, Butter C, Deharo JC, Kutarski A, Rinaldi CA, et al. The European Lead Extraction ConTRolled (ELECTRa) study: a European Heart Rhythm Association (EHRA) registry of transvenous lead extraction outcomes. *Eur Heart J*. 2017;38:2995–3005.
- Benak A, Kohari, M. Management of cardiac implantable electronic device infection using a complete interdisciplinary approach. 2021. <https://doi.org/10.1007/s00399-020-00728-1>.
- Al-Hijji MA, et al. Outcomes of lead extraction without subsequent device reimplantation. *Europace*. 2017;19:1527–34.
- Döring M, Hienzsch L, Ebert M, Lucas J, Dages N, Kühl M, et al. Extraction of infected cardiac implantable electronic devices and the need for subsequent re-implantation. *Int J Cardiol*. 2020;309:84–91. <https://doi.org/10.1016/j.ijcard.2019.12.044>.
- Gomes S, Cranney G, Bennett M, Giles R. Long-term outcomes following transvenous lead extraction. *PACE - Pacing Clin Electrophysiol*. 2016;39:345–51.
- Merchant FM, et al. Predictors of long-term survival following transvenous extraction of defibrillator leads. *PACE - Pacing Clin Electrophysiol*. 2015;38:1297–303.
- Diemberger I, Biffi M, Lorenzetti S, Martignani C, Raffaelli E, Ziacchi M, et al. Predictors of long-term survival free from relapses after extraction of infected CIED. *Europace*. 2018;20:1018–27.
- Deckx S, Marynissen T, Rega F, Ector J, Nuyens D, Heidbuchel H, et al. Predictors of 30-day and 1-year mortality after transvenous lead extraction: a single-centre experience. *Europace*. 2014;16:1218–25.
- Bongiorni MG, et al. 2018 EHRA expert consensus statement on lead extraction: recommendations on definitions, endpoints, research trial design, and data collection requirements for clinical scientific studies and registries: Endorsed by APHRS/HRS/LAHRs. *Europace*. 2018;20:1217–1217j.
- Blomström-Lundqvist C, Traykov V, Erba PA, Burri H, Nielsen JC, Bongiorni MG, et al. European Heart Rhythm Association (EHRA) international consensus document on how to prevent, diagnose, and treat cardiac implantable electronic device infections—endorsed by the Heart Rhythm Society (HRS), the Asia Pacific Heart Rhythm Society (APHRS), th. *Europace*. 2020;22:515–49.
- Kusumoto FM, Schoenfeld MH, Wilkoff BL, Berul CI, Birgersdotter-Green UM, Carrillo R, et al. 2017 HRS expert consensus statement on cardiovascular implantable electronic device lead management and extraction. *Heart Rhythm*. 2017;14:e503–51.

20. Hinkle LE, Thaler HT. Clinical classification of cardiac deaths. *Circulation*. 1982;65:457–64.
21. Milman A, et al. Predictors of short-term mortality in patients undergoing a successful uncomplicated extraction procedure. *J Cardiovasc Electrophysiol*. 2020;0–2. <https://doi.org/10.1111/jce.14436>.
22. Maytin M, Jones SO, Epstein LM. Long-term mortality after transvenous lead extraction. *Circ Arrhythm Electrophysiol*. 2012;5:252–7.
23. Bontempi L, et al. The MB score: a new risk stratification index to predict the need for advanced tools in lead extraction procedures. *EP Eur*. 2020;1–9. <https://doi.org/10.1093/europace/eaab027>.

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