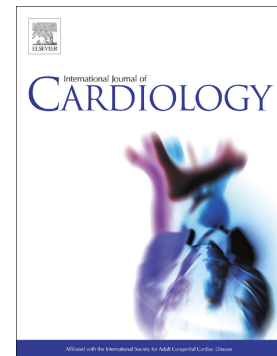


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# Leadless Micra Pacemakers: Estimating Long-Term Longevity. A real word data analysis

**Short Title:** longevity in leadless pacemaker

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\* This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation

**Statements and Declarations**

**Data Availability:** The data that support the findings of this study are available from the corresponding author, DC, upon reasonable request.

**Conflict of Interest:** C. Tondo receives lecture and proctor fees from Boston Scientific, Abbott, Bisoense Webster. Claudio Tondo serves in Medtronic and Boston Scientific Advisory Boards. P. de Filippo receives Consultant fees and travel support from Medtronic, Boston Scientific, Abbott, and Biotronik as well as honoraria and advisory board participation for Medtronic and Abbott. No other conflicts to disclose.

**Funding Sources:** No funding sources were involved in the research.

**Ethical Approval:** This project was approved by each site's Institutional Review Board and Local Ethics Committees.

**Informed Consent:** Each patient included in the One Hospital ClinicalService project provided informed consent for the data collection and analysis.

**Authorship:** All authors contributed to the study conception and design. Material preparation and data collection were performed by all authors. The first draft of the manuscript was written by Domenico Carretta and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**ABSTRACT**

**BACKGROUND:** Although leadless pacemakers have demonstrated satisfactory safety and efficacy, there is limited published data regarding the estimated lifespan in real word clinical scenarios.

**METHODS:** Between May 2015 and September 2023, all consecutive patients who underwent implantation of a single-chamber leadless Micra pacemaker were included in the One Hospital ClinicalService project and systematically tracked through remote monitoring at 15 Italian cardiology sites. Data on procedures, complications, electrical parameters, and estimated battery longevity were collected at baseline and annually during follow-up (FU). Additionally, virtual battery longevity (VBL) was calculated as the sum of the actual battery life consumed and the predicted remaining longevity ( $VBL = \text{months consumed} + \text{months predicted}$ ), providing an estimate of the device's total battery lifespan.

**RESULTS:** Patient and device data were gathered from 391 patients. Over a median follow-up period of 33.9 months (with interquartile range from 17.5 to 52.0 months), one patient experienced battery depletion. When examining VBL across all patients, the median VBL at baseline was 172 months (with a I-III interquartile range of 146 to 200 months), and VBL remained consistent or greater from the time of implantation up to seven years post-implant. The strongest predictor of VBL depletion within 8 years was capture threshold at implant greater than 1 V @ 0.24ms

**CONCLUSION:** In clinical practice, leadless pacemakers appear to have a median expected longevity ranging from 14 to 17 years. Having a stimulation threshold less than or equal to 1 V @ 0.24 ms seems to be an excellent predictor of increased longevity.

**Keywords:** leadless pacemaker, transcatheter pacing system, longevity, battery depletion

## INTRODUCTION

The Micra Transcatheter Pacing System (Micra, manufactured by Medtronic Inc, Minneapolis, Minnesota, US), an intracardiac leadless pacemaker, has been introduced as a substitute for the conventional transvenous pacemaker. Its aim is to eliminate complications associated with leads [1] and the device pocket.

While leadless Micra pacemakers have shown satisfactory safety and efficacy, [1,6] there remains a lack of comprehensive published data concerning their estimated lifespan in real world clinical settings. Despite their promising performance, uncertainties persist regarding their long-term durability and reliability. The battery longevity of these devices is crucial for end-of-life management, given that the encapsulation of the device is unpredictable and extraction techniques are not yet standardized. [2,7]

Historically, discrepancies between predicted and actual battery longevity in pacemakers and other implantable cardiac devices have been reported, with real-world data sometimes showing both shorter and longer durations than expected. [8] These variations can be influenced by device usage, programming settings, and patient-specific factors, as well as potential battery dysfunctions. Notably, such discrepancies have been observed in cardiac resynchronization devices, highlighting the complex interplay between theoretical estimations and real-world performance. [8-10]

Therefore, the purpose of this analysis is to assess the battery longevity of leadless Micra devices in clinical practice, using both actual and estimated consumption data.

## METHODS

Between May 2015 and September 2023, consecutive patients meeting the criteria for a class I indication for permanent cardiac pacing [2] received a leadless Micra implant at 15 Italian sites participating in the One Hospital ClinicalService project. All patients were prospectively monitored according to the clinical practice of each center, which involved regular in-hospital visits and remote management facilitated by a device monitoring system (Carelink, Medtronic Inc.). The One Hospital ClinicalService is clinical data repository for an integrated network consortium of cardiac hospitals with the shared goal of evaluating and improving the usage of Medtronic medical therapies in clinical practice through the mutual collection, examination, and analysis of pooled data. In this project, an independent scientific committee of physicians prospectively identifies key clinical questions on a yearly basis for analysis and dissemination to improve knowledge about applied therapies and to optimize patients' outcomes. This project was approved by each

site's Institutional Review Board and Local Ethics Committees. The design conforms to the principles outlined in the 1975 Declaration of Helsinki as reflected in the *a priori* approval by the institution's human research committee. Each patient included in the One Hospital ClinicalService project provided informed consent for the data collection and analysis.

The objective of this analysis was to assess the device battery longevity in the settings of clinical practice, considering the actual usage and estimation of residual battery at each year of follow-up for both Micra VR and Micra AV devices. Additionally, the virtual battery longevity (VBL) was calculated as the sum of the actual battery life consumed and the predicted remaining longevity ( $VBL = \text{months consumed} + \text{months predicted}$ ), providing an estimate of the device's total battery lifespan. Furthermore, predictors associated with reduced longevity have been evaluated.

### **Data collection and follow-up**

At the time of Micra implantation, a baseline assessment was conducted, encompassing the collection of demographic details, medical history, cardiovascular medication data, and a 12-lead ECG. The implantation procedure for Micra has been described previously. [1, 2-6] Each participating center adhered to their standard-of-care practices and methodologies during the implantation process. The automatic capture management algorithm was active to adapt the voltage output to the ventricular threshold, and the safety margin was 0.5V. The leadless devices were all programmed to minimize the percentage of unnecessary pacing. Subsequent follow-up visits adhered to the standard-of-care and clinical protocols of the participating centers. Typically, the initial follow-up visit post-implantation occurred within the first month to optimize pacemaker programming and verify all electrical system parameters, including estimated battery longevity, followed by visits every 6 months. Additionally, device transmissions of electrical data were scheduled at least every 6 months. Each follow-up (FU) examination included a review of cardiovascular symptoms, ECG assessment for arrhythmic events, device electrical measurements, and evaluation of cardiovascular drug therapy. Moreover, data on minimum, median and maximum estimated battery longevity were collected from devices at each in-person or remote Follow up. All serious procedural, peri-procedural, and post-procedural complications were documented.

### **Statistical analysis**

Descriptive statistics were used to summarize all results. These include mean and standard deviation, minimum, maximum and median with interquartile range (IQR) for continuous variables and counts and percentages for categorical variables. Variables were also represented graphically, using box-plots and bar charts for continuous and categorical variables, respectively, whenever appropriate. Time to FU was calculated from implant date and expressed in months according to the following formula: Time to FU (months) = (Last contact date – Implant date+1) / 30.4. Time-to-first event analyses were described using Kaplan-Meier estimates. To find predictors of early battery depletion, a Cox regression was used for both univariate and multivariate analyses, and the proportional hazard hypothesis was tested. A set of a priori potential predictors was assessed. Possible collinearity among these variables were tested by Spearman-Rho, where a correlation coefficient >0.80 and/or clinical judgment determined covariate exclusion. The final set of potential predictors was then included in the multivariate model. The Hazard Ratios (HRs) and 95% confidence intervals (95% CIs) were estimated for all initial potential predictors. The multivariate Cox regression model used a stepwise selection with entry at 0.30, stay criteria at 0.10, and virtual battery longevity as the dependent variable. A Receiver Operating Characteristic (ROC) analysis was performed to identify the optimal ventricular capture threshold to predict early battery depletion.

All tests were two-sided and a p-value < 0.05 was considered statistically significant. SAS software, version 9.4, (SAS Institute Inc., Cary, NC, USA) was used to perform all statistical analyses.

## RESULTS

### Baseline characteristics

A total of 391 patients underwent a Micra implant. Baseline characteristics of the patient population are summarized in **Table 1**. The mean age of the analysed population was 71 years, with 70% being male. Less than 10% of patients had a history of heart failure, and only 2.9% presented with advanced New York Heart Association Classification (NYHA class) at baseline. Nearly half of the population had a history of atrial fibrillation (AF), with permanent AF in 22% of cases. 35% of patients were implanted due to advanced block, while in 33% of cases, the indication was sinus node disease. In the remaining cases, the primary reason for implantation was AF conducted in the ventricle. Fifty-four patients were implanted with Micra AV, while the remaining received Micra VR. The procedural implantation details are outlined in **Table 2**. Specifically, the mean impedance was  $714.0 \pm 198$  ohms, with a median value of 670 ohms and an

interquartile range of 580.0 to 800.0 ohms. A total of 14.9% of patients had an impedance greater than 900 ohms, while only two patients (0.3%) had an impedance below 400 ohms. No serious peri-procedural complications were reported in this population.

### **Follow up And Longevity data**

During a median FU time of 33.9 (I-III Interquartile range: 17.5-52.0), 3 events leading to hospital admission occurred: 2 instances of myocardial infarction (MI) and 1 early battery depletion at 1815 days post-implant due to elevated implant thresholds (3.5 V @ 0.24 ms). Expected battery longevity mean time at each follow up is shown in the **Figure 1 and Table 3**. Overall results showed that the mean longevity time decreased from baseline to 8 years. No sudden battery discharge events occurred.

The virtual battery life (VBL), defined as the estimated expected device longevity plus the actual battery life, was 14 years (median value: 172 month, I-III interquartile: 146-199 months) at implantation. **Figure 2** illustrates the trend of virtual battery life over time, while **Panel B** depicts the survival curve. Unadjusted freedom from VBL depletion at 16 years was 56.5 % (95% CI 51.5- 61.3). **Table 4** delineates both the univariate and multivariate associations between VBL depletion and clinical baseline characteristics, highlighting the clinical predictors of VBL depletion after the TPS implant procedure. Cox regression analysis revealed that certain baseline and device data at implantation were predictive of VBL depletion through univariate analysis, including Impedance, percentage of Ventricular pacing, right ventricle Sensing, and capture Threshold. Multivariate analysis corroborated capture threshold value as an independent predictor of VBL depletion recurrence (HR 2.71, 95% CI: 1.78-4.14;  $p < 0.001$ ), while adjusting for baseline differences. To ascertain the optimal cut-off value of capture Threshold at implantation for predicting VBL depletion within less than 8 years, a ROC analysis was conducted. The optimal cut-off, maximizing sensitivity and specificity, was found to be 1.06V @0.24 ms, with an AUC of 0.9,  $p < 0.001$ . **Figure 3**

### **Longevity sub-analysis**

Limiting the analysis to the subset of 337 patients with Micra VR, the median longevity at implantation was 165.4 (151.0-190.1) months, whereas in the Micra AV subgroup (consisting of 54 patients) was 126.8 (113.0-151.6) months. Unadjusted freedom from VBL depletion in Micra VR and Micra AV patients is shown in the Appendix (**Figure 4 Panel A and B**)

## DISCUSSION

The current analysis examines 391 patients implanted with a TPS. The longevity of leadless pacemakers is a crucial factor, especially considering their end-of-life management. Currently, there are no established procedures or guidelines to aid clinicians in deciding when to explant a device or add another. [2, 11] Factors such as patient age, device location, presence of previous devices, the presence of encapsulation, are considered in this decision-making process. Naturally, the longer the longevity of an intracardiac device, the less need there will be for replacement over time.

According to technical product specification, the estimated battery longevity of the TPS ranges between 4.7 and 15 years, depending on factors such as stimulation percentage, pacing output values, and impedance in the device-cardiac tissue interface [12]. The aim of this analysis was to evaluate the actual lifespan of devices in clinical practice, calculating the expected device lifespan for each year of follow-up. To simulate the battery lifespan of leadless pacemakers, we considered the variable VBL for each year of follow-up, defined as the sum of the remaining estimated battery life in years and the years of follow-up. This battery life estimate demonstrates a projected device lifespan significantly greater than the 12 years stipulated in the manual. In fact, the current analysis described a median virtual battery longevity of approximately 16 years. The device type influences this data, with Micra VR devices averaging around 16 years and Micra AV devices around 12 years. Recently, Breeman et al. demonstrated in a cohort of 105 patients with Micra VR that, within a follow-up period of up to 5 years, the expected battery longevity exceeded the manufacturer's predicted value of >8 years for the majority of patients, indicating concordance between observed and predicted battery longevity for the Micra VR model. [13] Moreover, an analysis on 26,698 patients showed that the Median projected battery longevity for the overall cohort was 13.7 years (IQR: 12.4 - 15.3 years) with 91.9% of devices exceeding 10 years. Among patients with >90% pacing burden (N=11,717), median projected battery longevity was 12.6 years (IQR: 11.6-13.4) with 87.2% of devices exceeding 10 years. [14] Also, in the most recent update of the Micra VR post approval registry, a Monte Carlo analysis on the projected longevity 5 years post implant showed a median remaining battery life of 6.8 years with 83.8% of patients having at least 5 years of additional projected longevity. [15] During 5 years of follow-up, our results showed a median remaining battery life higher than 10 years with 98.7% of patients having at least 5 years of additional projected longevity. These projections may not be directly comparable but nonetheless

they confirm that our real world findings corroborate the previous results and suggest an increased longevity. Garweg et al, among 5456 patients with Micra AV with at least 180 days of device follow-up, presented that the median projected longevity for Micra AV was 10.9 years [16]. There is no difference in the size or chemical composition of the device battery. Therefore, one of the primary reasons for the difference in longevity between the VR and AV models is the battery consumption resulting from the higher computational burden due to the accelerometer data analysis happening in a specific time frame during every cardiac cycle. Additionally, it is important to consider the pacing percentage, which is influenced by the specific characteristics of the patient's conduction disorder.

In our dataset, the ventricular capture threshold emerged as the only actionable baseline predictor for identifying patients at risk of early battery depletion. This is particularly relevant in younger patients, where careful monitoring and maintaining a capture threshold of  $\leq 1V @ 0.24\text{ ms}$  may be crucial. Although pacing current directly influences battery consumption, it is not explicitly reported by the device and can only be inferred through arithmetic calculation, making it less visible and accessible to physicians during implantation or follow-up. The calculations that yielded the values reported in Table 2 are based on Ohm's law. Additionally, pulse width plays a significant role in battery consumption; indeed, a shorter pulse width results in lower energy consumption. In Micra and Micra AV devices, the nominal pulse width is set to 0.24 ms. This value is closer to the chronaxie of cardiac cells compared to the usual 0.4 ms of transvenous devices, making it more energy-efficient [17]. Furthermore, the capture management algorithm in these devices adjusts the pacing output by adding a programmable safety margin (default, +0.5V) to the highest threshold that was measured in the last two weeks. Due to the collinearity between current drain, capture threshold, and pacing impedance, we decided to retain the latter two variables in the Cox regression analysis. Capture threshold and pacing impedance represent actual measurements rather than estimates and have historically been used in similar statistical analyses.

Pacing percentage undoubtedly plays a significant role in device longevity. However, only variables measured at the time of implantation were included in the Cox regression analysis, as pacing percentage can fluctuate considerably during follow-up due to disease progression, device programming, or lifestyle factors. In addition to paying particular attention to the implantation area and electrical measurements, future improvements in device and battery technology and energy-saving software will need to be implemented to

ensure increased longevity of intracardiac devices. The second-generation Micra VR has a projected battery longevity of 17 years possibly adding to the benefit of this technology [16]. Robust longevity data could allow for a broader selection of patients suitable for leadless pacing.

## **LIMITATIONS**

Our findings may be biased due to the limited number of patients analyzed. However, we presented data derived from the real-world clinical practice of multiple centers, representing diversity in electrical measurements, pacing percentages, and patient management protocols. Data on a larger population and with a longer follow-up are needed to better understand the actual battery life of these devices. This analysis excludes minor complications that neither necessitated hospitalization nor led to a notable extension of hospital stay. As a result, certain events might be underreported, including asymptomatic pericardial effusion, minor groin site injuries, or capture threshold increases managed by pacemaker reprogramming alone. An additional limitation is that the pacing current was not used to assess battery consumption. Although current directly influences battery longevity, it is not readily available in device data readings and is therefore not typically used in routine clinical practice during implantation or follow-up.

## **CONCLUSION**

In our multicenter real-world prospective data, Micra leadless pacemakers appear to have a battery longevity consistent or greater than expected. Having an implant capture threshold lower or equal to 1 V @ 0.24 ms seems to be a strong predictor of increased longevity.

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**Figure Legends**

**Figure 1.** Expected battery Longevity Mean Time distribution in years over the time according to data devices.

**Figure 2:** The virtual battery life (VBL) is calculated as the sum of the actual battery life consumed and the predicted remaining longevity ( $VBL = \text{months consumed} + \text{months predicted}$ ), providing an estimate of the device's total battery lifespan.

**Panel A:** Trend of VBL over time.

**Panel B:** Kaplan-Meier survival curves illustrating overall survival from VBL depletion in patients with Micra VR or Micra AV.

**Figure 3.** Receiver Operating Characteristic (ROC) curve analysis depicting the sensitivity and specificity of Ventricular capture threshold value in identifying early virtual battery depletion. The area under the curve (AUC) is indicative of the classifier's discriminatory power. Area under the curve: 0.932; 95% CI: 0.884-0.979.

**Table 1:** Baseline clinical characteristics of the total population of patients

| <b>Variables</b>                              | <b>TOTAL<br/>(N = 391)</b> |
|-----------------------------------------------|----------------------------|
| <b>Demographics</b>                           |                            |
| <b>Age at Micra implant (yrs)</b>             | 71.2 ± 16.9                |
| <b>Gender (Male)</b>                          | 70.1% (274)                |
| <b>BMI (kg/m<sup>2</sup>)</b>                 | 26.8 ± 4.4                 |
| <b>Medical history</b>                        |                            |
| <b>History of HF</b>                          | 9.2% (36)                  |
| <b>NYHA 3/4</b>                               | 1.8% (7)                   |
| <b>History of AT/AF</b>                       | 48.6% (190)                |
| <b>Paroxysmal AF</b>                          | 10.7% (42)                 |
| <b>Persistent AF</b>                          | 4.6% (18)                  |
| <b>Permanent AF</b>                           | 33.2% (130)                |
| <b>Ischemic Cardiopathy</b>                   | 5.1% (20)                  |
| <b>History of syncope</b>                     | 36.8% (144)                |
| <b>History of Stroke/TIA</b>                  | 5.9% (23)                  |
| <b>Hypertension</b>                           | 65.2% (255)                |
| <b>Diabetes</b>                               | 19.9% (78)                 |
| <b>Chronic Kidney Disease</b>                 | 16.6% (65/391)             |
| <b>CHADS<sub>2</sub> ≥ 2</b>                  | 59.7% (223)                |
| <b>CHA<sub>2</sub>DS<sub>2</sub>-VASc ≥ 4</b> | 37.5% (146)                |
| <b>COPD</b>                                   | 6.6% (26)                  |
| <b>LVEF (%)</b>                               | 56.2 ± 6.9                 |
| <b>Conduction Disease</b>                     |                            |
| <b>1st grade AV block</b>                     | 9.2% (36)                  |
| <b>2nd grade AV block</b>                     | 11.5% (45)                 |
| <b>3rd grade AV block</b>                     | 19.7% (77)                 |
| <b>RBBB</b>                                   | 10.2% (40)                 |
| <b>LBBB</b>                                   | 4.1% (16)                  |
| <b>Left Hemiblock</b>                         | 5.6% (22)                  |
| <b>SND</b>                                    | 51.9% (203)                |
|                                               | 30.0 - 76.0                |
| <b>Medication at baseline</b>                 |                            |
| <b>Antiplatelets</b>                          | 23.1% (90)                 |
| <b>Anticoagulant</b>                          | 53.2% (208)                |
| <b>ACE inhibitor and/or ARB2</b>              | 35.2% (137)                |

| <b>Variables</b> | <b>TOTAL<br/>(N = 391)</b> |
|------------------|----------------------------|
| <b>Diuretics</b> | 39.0% (152)                |

**Table 2** Procedural times and data of the total population of patients

| <b>Procedural Data</b>                                                               | <b>TOTAL<br/>(N = 577)</b> |
|--------------------------------------------------------------------------------------|----------------------------|
| <b>Duration of the hospitalization (Days) mean <math>\pm</math> SD</b>               | 4.9 $\pm$ 4.3              |
| <b>Total Procedural Time (minutes) mean <math>\pm</math> SD</b>                      | 50.7 $\pm$ 20.1            |
| <b>Fluoroscopy Time (minutes)<br/>mean <math>\pm</math> SD</b>                       | 7.4 $\pm$ 5.8              |
| <b>Time procedure end to Patient's mobility (Hours)<br/>mean <math>\pm</math> SD</b> | 28.7 $\pm$ 17.4            |
| <b>Device Type</b>                                                                   |                            |
| <b>Micra VR (% , (n))</b>                                                            | 86.2% (337)                |
| <b>Micra AV (% , (n))</b>                                                            | 13.8% (54)                 |
| <b>Implant Electrical Parameter</b>                                                  |                            |
| <b>Pacing Impedance (Ohm),</b>                                                       | 714.0 $\pm$ 198            |
| <b>RV Sensing (mV), mean <math>\pm</math> SD</b>                                     | 10.8 $\pm$ 5               |
| <b>Ventricular pacing threshold (V@ 0.24 ms), mean <math>\pm</math> SD</b>           | 0.8 $\pm$ 0.5              |
| <b>Current (mA)</b>                                                                  | 1.3 $\pm$ 1.9              |

**Table 3** Electrical parameters and battery longevity at each year of follow-up.

| Electrical parameters and battery longevity | TOTAL        |
|---------------------------------------------|--------------|
| <b>Implant (N=391)</b>                      |              |
| Impedance (Ohm)                             | 714.0 ± 198  |
| Sensing (mV)                                | 10.8 ± 5.1   |
| Threshold (V normalized at 0.24 ms)         | 0.8 ± 0.9    |
| Ventricular pacing (%)                      | 24.7 ± 34.8  |
| Longevity Max Time                          | 162.2 ± 44.5 |
| Longevity Min Time                          | 142.8 ± 39.4 |
| Longevity Mean Time                         | 152.5 ± 42.0 |
| <b>1 Year (N=339)</b>                       |              |
| Impedance (Ohm)                             | 535.2 ± 98   |
| Sensing (mV)                                | 11.9 ± 5     |
| Threshold (V normalized at 0.24 ms)         | 0.7 ± 0.6    |
| Ventricular pacing (%)                      | 29.3 ± 36.0  |
| Longevity Max Time                          | 168.2 ± 38.7 |
| Longevity Min Time                          | 146.9 ± 34.3 |
| Longevity Mean Time                         | 157.5 ± 36.5 |
| <b>2 Years (N=260)</b>                      |              |
| Impedance (Ohm)                             | 527.4 ± 98   |
| Sensing (mV)                                | 11.8 ± 5.6   |
| Threshold (V normalized at 0.24 ms)         | 0.8 ± 0.5    |
| Ventricular pacing (%)                      | 26.5 ± 25    |
| Longevity Max Time                          | 160.5 ± 34   |
| Longevity Min Time                          | 138.3 ± 30   |
| Longevity Mean Time                         | 149.7 ± 32   |
| <b>3 Years (N=200)</b>                      |              |
| Impedance (Ohm)                             | 509.1 ± 83   |
| Sensing (mV)                                | 10.9 ± 5.5   |
| Threshold (V normalized at 0.24 ms)         | 0.8 ± 0.5    |
| Ventricular pacing (%)                      | 27.7 ± 36    |
| Longevity Max Time                          | 149.5 ± 34   |
| Longevity Min Time                          | 127.9 ± 29.9 |
| Longevity Mean Time                         | 138.7 ± 32.0 |
| <b>4 Years (N=142)</b>                      |              |
| Impedance (Ohm)                             | 503.6 ± 78.6 |

| Electrical parameters and battery longevity | TOTAL        |
|---------------------------------------------|--------------|
| Sensing (mV)                                | 9.9 ± 4.8    |
| Threshold (V normalized at 0.24 ms)         | 0.8 ± 0.6    |
| Ventricular pacing (%)                      | 25.4 ± 34.5  |
| Longevity Max Time                          | 140.3 ± 36   |
| Longevity Min Time                          | 118.3 ± 32   |
| Longevity Mean Time                         | 129.4 ± 34   |
| 5 Years (N=79)                              |              |
| Impedance (Ohm)                             | 500.6 ± 82.1 |
| Sensing (mV)                                | 10.2 ± 5.1   |
| Threshold (V normalized at 0.24 ms)         | 0.8 ± 0.8    |
| Ventricular pacing (%)                      | 30.6 ± 34.8  |
| Longevity Max Time                          | 130.0 ± 37.3 |
| Longevity Min Time                          | 108.9 ± 32.4 |
| Longevity Mean Time                         | 119.4 ± 34.8 |
| 6 YEARS (N=41)                              |              |
| Impedance (Ohm)                             | 500.7 ± 67.1 |
| Sensing (mV)                                | 9.6 ± 4.2    |
| Threshold (V normalized at 0.24 ms)         | 0.9 ± 0.9    |
| Ventricular pacing (%)                      | 36.3 ± 38.5  |
| Longevity Max Time                          | 114.4 ± 41.6 |
| Longevity Min Time                          | 94.5 ± 35.7  |
| Longevity Mean Time                         | 104.4 ± 38.7 |
| 7 YEARS (N=12)                              |              |
| Impedance (Ohm)                             | 470.0 ± 61.3 |
| Sensing (mV)                                | 8.6 ± 4.8    |
| Threshold (V normalized at 0.24 ms)         | 0.7 ± 0.4    |
| Ventricular pacing (%)                      | 52.3 ± 36.1  |
| Longevity Max Time                          | 104.2 ± 29.7 |
| Longevity Min Time                          | 84.5 ± 26.1  |
| Longevity Mean Time                         | 94.4 ± 27.9  |

**Table 4.** Univariate and multivariable analysis of clinical outcomes against baseline characteristics (Age and Sex) and electrical measurements at implant with significant univariate association.

| Parameter                           | Univariate                 |                  | Multivariate               |                  |
|-------------------------------------|----------------------------|------------------|----------------------------|------------------|
|                                     | Odd Ratio (OR)<br>(95% CI) | p-value          | Odd Ratio (OR)<br>(95% CI) | p-value          |
| Impedance (Ohm)                     | 0.99 (0.99-1.00)           | <b>0.004</b>     | 1.00 (0.99-1.00)           | 0.374            |
| Impedance > 900 Ohm                 | 0.37 (0.05-2.86)           | 0.341            | -                          | -                |
| Sensing (mV)                        | 0.86 (0.74-0.99)           | <b>0.040</b>     | -                          | -                |
| Threshold (V normalized at 0.24 ms) | 2.98 (2.02-4.39)           | <b>&lt;0.001</b> | 2.71 (1.78-4.14)           | <b>&lt;0.001</b> |
| Age                                 | 1.04 (0.99-1.08)           | 0.107            | 1.04 (1.00-1.08)           | 0.083            |
| Gender (Female)                     | 0.35 (0.08-1.57)           | 0.171            | -                          | -                |

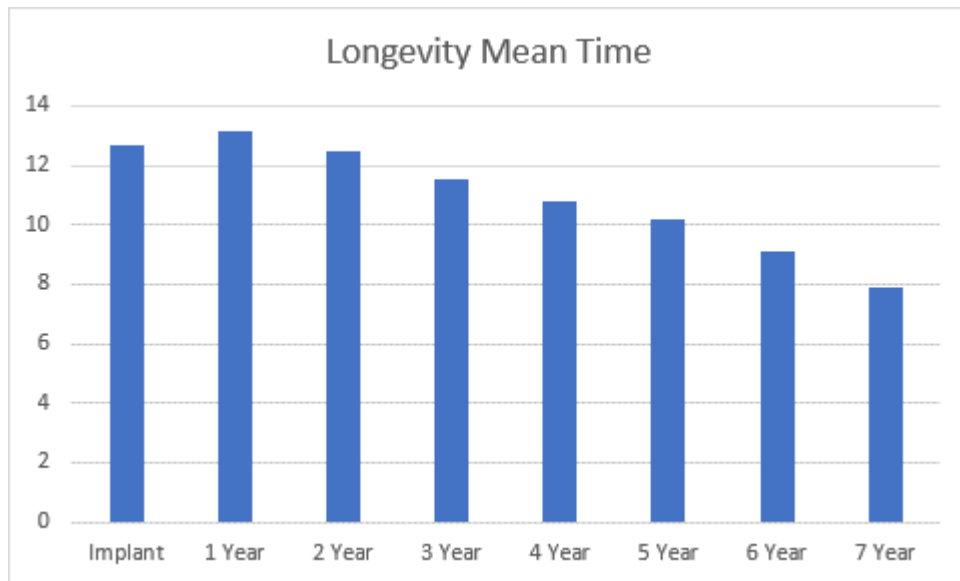
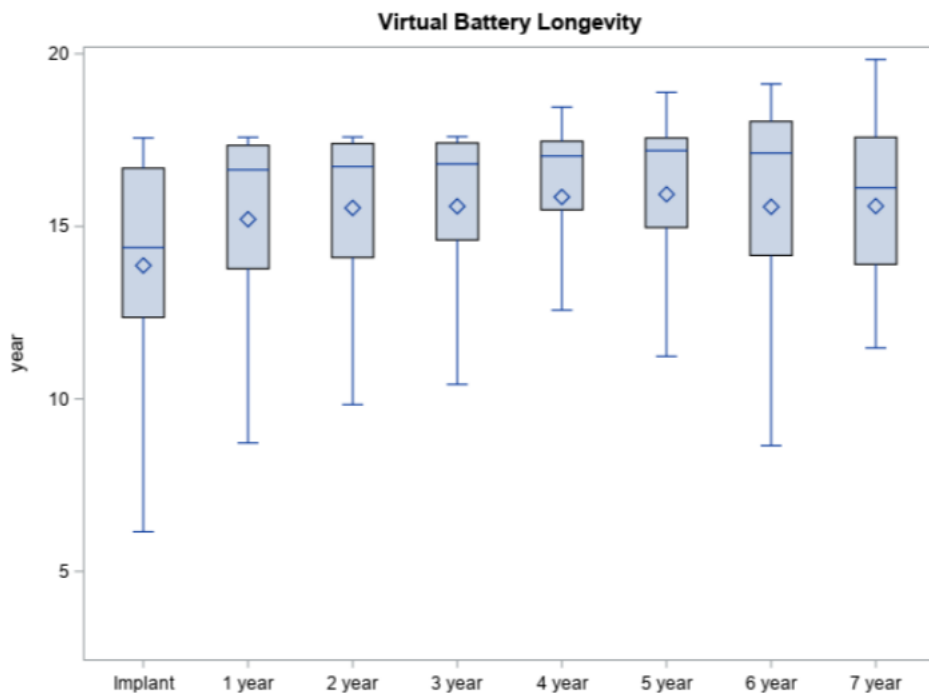
**Figure 1.****Figure 2 Panel A**

Figure 2 Panel B

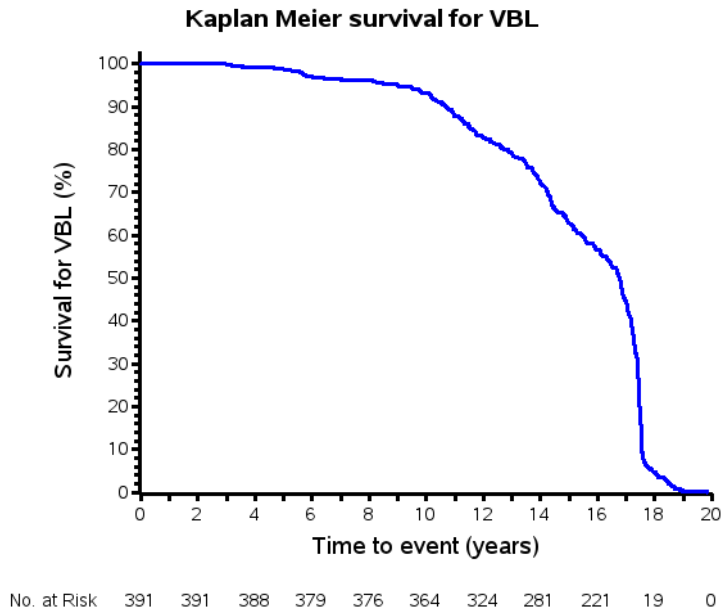
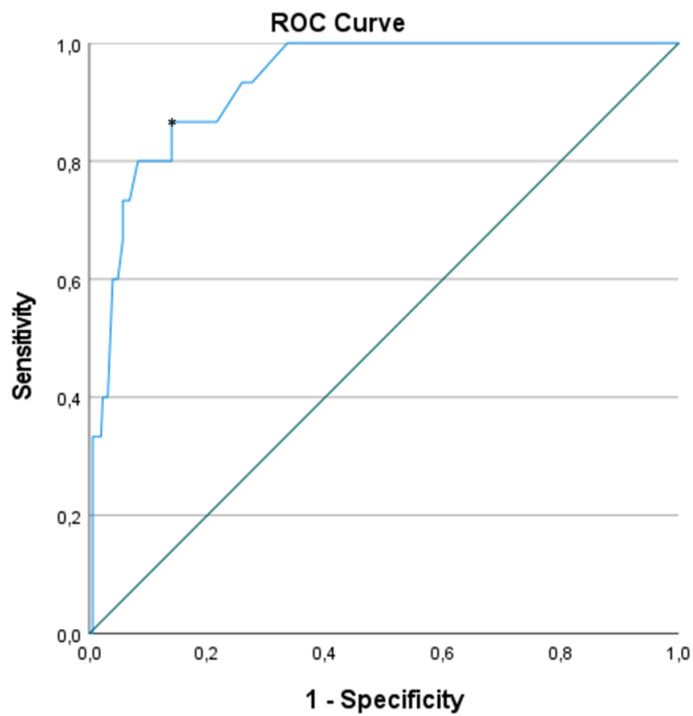


Figure 3



Journal Pre-proof

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## Highlights

- Median virtual battery life of leadless pacemakers reaches up to 16 years.
- Longevity observed in real-world data exceeds manufacturer predictions.
- Capture threshold  $\leq 1V$  @ 0.24ms is crucial for optimizing device longevity.
- Micra VR shows greater longevity than Micra AV, influenced by pacing needs