Διάρκεια ζωής των εμφυτεύσιμων ηλεκτρονικών συσκευών. Βέλτιστος προγραμματισμός για εξασφάλισή της.
EARLY POWER SOURCES

1950 decade
- Zinc-Mercury Cell

1965
- nuclear energy cells

late 1960s
- lithium-iodine

early 1970s
- Rechargeable Cells
- nickel-cadmium

today
major complication rate: 4.0%

minor complication rate: 7.4%
✓ over a longer 10-year period, the sensitivity analysis showed 2820 fewer replacement procedures and associated cost savings of SEK 249.3 million (around €24.93 million) for all defibrillators with extended battery life.
Limitations regarding CIED’s estimated longevity

✓ lack of standardized reporting by CIED manufacturers (different settings)
✓ pertinent information, such as battery capacity and chemistry, are sometimes kept proprietary and undisclosed
✓ CIEDs are largely superseded by newer models and technology at the time of reporting
✓ Real-world longevities will differ from predicted industry modeling
SR estimated longevity

✓ predicted longevity of an SR PPM (with all advanced features turned off) at 50% and 100% pacing load was **11 to 15 years** and **10 to 13 years**, respectively
✓ predicted longevity of a DR PPM device (with all advanced features turned off) at 50% and 100% pacing load was **9.5 to 13.5 years** and **8 to 11.5 years**, respectively

✓ Turning on advanced features such as blended rate response, prearrhythmia electrogram recording, and radiofrequency remote monitoring can reduce PPM longevity by **0.5 to 3.6 years**

*Heart Rhythm 2018;15:1756–1763*
✓ predicted longevity of an SR and DR ICD was **9.5 to 16 years** and **8.5 to 15 years**, respectively.
✓ Predicted longevity of CRT-D devices (with 15% A and 100%Bi-V pace at 60 bpm, 2.5 V, 0.40 ms; 500-U leads, sensor off, radiofrequency remote communication and home monitoring on) was **6.5 to 11 years**
“Real life” longevity of implantable cardioverter-defibrillator devices

Longevity of 4.9 ±1.6 years

✓ 8% demonstrate premature battery depletion by 3 years.

Longevity for CRT-D (mean, 3.8 years)
Product performance reports from all manufacturers significantly overestimated battery longevity by more than 20%, 6 years after device implantation.
SUPPLY-SIDE FACTORS
DEMAND-SIDE FACTORS

Non-modifiable factors:
✓ background current
✓ high voltage capacitor reformation

Modifiable factors:
✓ radiofrequency (RF) telemetry transmission
✓ electrogram storage
✓ pacing outputs
✓ pacing burden
✓ high-voltage shocks
Battery capacity

✓ Battery capacity is typically measured in ampere-hours (Ah, the electrical equivalent of 1 A delivered continuously for 1 hour)

✓ A larger battery capacity is associated with prolonged CRTD longevity in clinical use
Electrochemical cell

✓ Since early 1970's

✓ Low-power (specifically those without RF interrogation capability) are often Li/I2.

Battery chemistry

- ANODE
  - Li
- ELECTROLYTE
  - Conducts ions
- CATHODE
  - SVO
  - CFx
  - SVO-CFx
  - MnO2
Battery chemistry

Li/SVO, Li/SVOCFx hybrid

Battery voltage

Internal resistance

Charge time

ERI at 70% discharge

Li/MnO2

✓ Voltage > 2.8 V
✓ Stable internal resistance
✓ ERI at 90% discharge
Capacitor Reformation

Deformation: degradation of the oxide layer

- The performance can be maintained by reforming or charging the capacitors regularly.
- The oxide layer can be “healed” or “repaired” by passing an electric current through the capacitor periodically.
- Each reformation consumes 0.5–1% of the total battery capacity.
- 5–8% of the overall longevity.

✓ long charge time
✓ Heating
✓ Explosion
## high-voltage capacitors

<table>
<thead>
<tr>
<th>Aluminum Electrolytic</th>
<th>Tantalum Electrolytic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less stable oxide</td>
<td>More stable oxide</td>
</tr>
<tr>
<td>• Need periodic reformation</td>
<td>• No need for periodic reformation</td>
</tr>
<tr>
<td>• ↓ Device longevity</td>
<td>• No adverse impact on device longevity</td>
</tr>
<tr>
<td>Higher breakdown voltage (~450 V)</td>
<td>Lower breakdown voltage (~250 V)</td>
</tr>
<tr>
<td>• Two in series for transvenous defibrillation</td>
<td>• Three in series for subcutaneous defibrillation</td>
</tr>
<tr>
<td>Generally flat (uniformly thick curved edges only)</td>
<td>Any shape (sloped curved edges allowed)</td>
</tr>
<tr>
<td>Lighter</td>
<td>Heavier by ~10–15 g</td>
</tr>
<tr>
<td>Abundant raw materials</td>
<td>Rare raw materials</td>
</tr>
<tr>
<td>Cheaper</td>
<td>More expensive</td>
</tr>
</tbody>
</table>

*Images: *
- **A**: Aluminium electrolytic capacitor
- **B**: Tantalum electrolytic capacitor
There is a direct relationship between increasing complexity of manufacturing and increasing energy density, progressing from spiral wound (least energy dense) to stacked plate (most energy dense).

For maximum power capability and energy density, and minimum internal resistance, the electrodes need to have large surface areas in close proximity.

Battery Architecture
✓ Every CIED has a background current that powers microprocessors.

✓ Most devices have a greater overall background current drain than all dynamic factors

✓ Significant effect on device longevity.

✓ Some patient-specific factors, such as the presence of frequent ectopy, can lead to increased microprocessor usage.
4% to 8% of the usable battery capacity of a contemporary ICD/CRT-D is used on RF telemetry.

If RF telemetry session is not “ended,” 0.6% to 1.0% of the battery capacity could be used in one setting.

“timeout” after a period of inactivity, limiting the potential current drain of a prolonged RF telemetry session.
Continuous unfiltered electrogram storage can shorten device longevity by 16%

Continuous filtered electrogram storage has a smaller effect on device longevity and is often programmed on and not able to be turned off in devices in which it is present.
pulse amplitude and pulse duration

Strength-Duration Curves

- **rheobase**: The lowest possible pacing output voltage that captures myocardium at an infinite pulse duration.

- **chronaxie**: The output and pulse duration of the minimum current drain that can capture myocardium.
✓ avoid increasing pacing output past certain thresholds (around 2.5 V and 5.0 V)

✓ Pacing impulses greater than the battery voltage (typically >2.5 V) require voltage amplification

✓ voltage multiplier  Two or three capacitors are charged

   Increased current drain
pulse amplitude programmed above the nominal value of 2.5 V or 5.0 V

**voltage doubler or tripler**

For example:

- Capture threshold is 1.5 V at a pulse width of 0.4 ms
- Setting: 3.0 V at a pulse width of 0.4 ms
- Capture threshold: 1.25 V at a pulse width of 0.6 ms
- Setting: 2.5 V at a pulse width of 0.6 ms

**battery current drain**
Threshold data are used either:
✓ on a beat-by-beat basis to ensure a paced response or
✓ intermittently to adjust output parameters.
✓ threshold tests are automatically performed with a programmable periodicity

‘x2safety margin’ vs Autocapture

expected benefit of AutoCapture was over 12 months
Minimizing ventricular pacing

✓ AVSH
✓ Av search
✓ MVP
✓ Search AV
✓ AICS
✓ VIP
✓ SafeR

Intrinsic Activity

increasing overall battery longevity
Single Chamber Hysteresis

- VVI pacer programmed toLower rate = 60 bpm (1000 ms)
- Single Chamber Hysteresis = 50 bpm (1200 ms)
- Interval after a paced beat is1000 ms
- Interval after a sensed beat is1200 ms
- Designed to encourage intrinsic activity

1200 ms Single Chamber Hysteresis Interval (Prolonging the escape interval after the VS allows more time for an intrinsic beat to occur)
✓ extending the AV and PV delays
Clinical evaluation of pacemaker automatic capture management and atrioventricular interval extension algorithm

### Table 3  Median percentage RV pacing with SAV+ ON vs. SAV+ OFF at 6-month follow-up

<table>
<thead>
<tr>
<th></th>
<th>All patients (n = 365)</th>
<th>SND without AVB (n = 219)</th>
<th>All AVB (excluding persistent 3° block) (n = 15)</th>
<th>3° AVB (n = 103)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAV+ OFF</td>
<td>99.8</td>
<td>99.7</td>
<td>99.9%</td>
<td>99.9%</td>
</tr>
<tr>
<td>SAV+ ON</td>
<td>4.6</td>
<td>1.5</td>
<td>50.2%</td>
<td>99.4%</td>
</tr>
</tbody>
</table>

### Table 4  Modelling results of longevity gains when using ACM, VCM, and SAV+ algorithms

<table>
<thead>
<tr>
<th>Programmed settings</th>
<th>Longevity gain (years)</th>
<th>Mean device longevity (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAV+ ON, ACM/VCM ON</td>
<td>1.9</td>
<td>9.2 ± 0.7</td>
</tr>
<tr>
<td>SAV+ ON, ACM/VCM OFF</td>
<td>1.0</td>
<td>8.3 ± 0.9</td>
</tr>
<tr>
<td>SAV+ OFF, ACM/VCM ON</td>
<td>1.3</td>
<td>8.6 ± 0.7</td>
</tr>
<tr>
<td>SAV+ ON, ACM OFF, VCM ON</td>
<td>1.1</td>
<td>8.4 ± 0.8</td>
</tr>
</tbody>
</table>
✓ Not all patients develop significant atrial chronotropic incompetence
✓ A single high voltage shock can consume approximately **0.5% to 1.0%** of the total battery capacity.

**conventional programming** (with a 2.5-second delay at 170 to 199 beats per minute and a 1.0-second delay at ≥200 beats per minute)

**delayed therapy** (with a 60-second delay at 170 to 199 beats per minute, a 12-second delay at 200 to 249 beats per minute, and a 2.5-second delay at ≥250 beats per minute)

**high-rate therapy** (with a 2.5-second delay before the initiation of therapy at a heart rate of ≥200 beats per minute)
Pacing Impedance

Current drain = \frac{V}{R}

✓ an increase in impedance by 100% decreases current drain by 50%

Low Impedance

High Impedance

![Graph showing current drain vs. pacing impedance]

- 500 ohms: 3.2 µAh/pulse
- 1000 ohms: 1.6 µAh/pulse
- 1500 ohms: 1.1 µAh/pulse
Quadripolar left ventricular leads

- 17 pacing vectors,
- Automated algorithms
- Increasing the chance of finding a low left ventricular capture threshold, which may ensure effective CRT delivery and possibly prolong device longevity.

Choosing a vector with an equal pacing threshold but higher impedance reduces current drain.
Contractility sensor-guided optimization of cardiac resynchronization therapy: results from the RESPOND-CRT trial

Sensor-Based CRT Optimization
SonR AV & VV Optimization Algorithm

Optimizing but also consuming
MULTIPLE POINT PACING

Optimizing but also consuming
Estimation of the effects of multipoint pacing on battery longevity in routine clinical practice

✓ maximal interelectrode cathode spacing is overall the best MPP configuration
✓ could only be obtained by accepting configurations with high pacing thresholds
AdaptivCRT Algorithm

Regular rhythm?
  yes
  Evaluate intrinsic conduction

Intrinsic AV conduction present and normal? HR ≤ 100 bpm?
  yes
  Adaptive LV pacing
  AV = 70% of the intrinsic AV but at least 40 ms prior to RVs
  no
  Adaptive BiV pacing
  Optimal AV and VV Delays?

Medtronic Viva XT CRT-D manual.

6th Annual Duke EP Summit
wireless remote monitoring of ICDs

- rapid detection of clinical events,
- reduction in inappropriate shocks
- potential survival benefit in those with daily transmission verification

may justify the impact of remote monitoring on battery longevity
CONCLUSIONS

✓ CIEDs for cardiac rhythm management remain one of the seminal medical achievements of the second half of the 20th century

✓ Prolonged longevity of CIEDs is needed to decrease the risks and costs associated with device replacement

✓ An industry-wide standardized reporting in predicted longevity for all CIED products is imperative

✓ Physicians and allied health professionals following CIEDs can improve device longevity by setting parameters in a saving energy way

✓ the evolution of progressively more sophisticated technologies, will inevitably create a cardiac device “once for a life”