Implantable Cardioverter-Defibrillators

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Ventricular Fibrillation

- Ventricular fibrillation – asynchronous contractions of the myocardial cells
- Cardiac output near zero
- Irreversible damage to the brain if not handled within approx. 5 min
- Therapy: defibrillation
  - Defibrillation Principle: the electrical shock stops ALL heart muscle fibers enter the refractory period at the same time
  - Normal heart rhythm may resume
Ventricular Fibrillation

Ventricular Fibrillation (VF)
Defibrillators

• External defibrillators – electric shock is carried out by passing a current pulse through large electrodes placed transthoracally

• Capacitive discharge defibrillators – the capacitor is charged and the stored energy is up to 400 J \( (E = CU^2 / 2) \)

• For maximal energy, the voltage ranges from 2 kV to 9 kV!
Defibrillation in Numbers

• Typical resistance of the chest (as measured through the defibrillator pads) is 50 ohm
• Typical capacitance of the high voltage capacitors is 80 µF
• \( E = CU^2 / 2 \rightarrow \) for \( E = 250 \text{ J}, U = 2500 \text{ V} \)
Capacitive discharge defibrillators

a) Block diagram of a capacitive discharge defibrillator

b) The waveform of the output pulse
Defibrillator currents

Waveforms of currents from different defibrillator types:

- a) AC defibrillator
- b) capacitive discharge
- c) serial resonant circuit
- d) rectangular
- e) with delay line
- f) biphasic
Biphasic Defibrillators

Energy levels of biphasic defibrillators are approx. twice lower than those of the monophasic apparatus.
Defibrillator – Pacemaker - Monitor

Portability of emergency equipment is necessary due to very short times available for interventions.

Reduction in size and weight while remaining the reliability is one of major concerns in new developments.
Defibrillator electrodes

a) Spoon shaped internal electrodes for direct application on heart during surgery
b) A paddle type electrode for use on the chest
Automatic External Defibrillator

Recent advances in technology have allowed people with little training to use automatic external defibrillators (AEDs) in an emergency when medical professionals are not present.
AED procedure

1. Get the defibrillator, PRESS the on/off button. The defibrillator will start speaking to you and will first tell you to remove all clothing from the patient’s chest.

2. The defibrillator will give voice instructions to open grey plastic case and peel off the white adhesive pads.

3. The defibrillator will give voice instructions to place the pads on the patient as clearly shown on the pictures printed on the pads.

4. The defibrillator will instruct you not to touch the patient and will spend a few seconds analysing the patient’s heart. If a shock is required the SHOCK button will flash and the voice instructions will tell you to push the flashing orange button.
Implantable Cardioverter - Defibrillators

Cardioversion - applying electrical shock to change an abnormal heartbeat into a normal one
Defibrillation - applying electrical shock to stop cardiac fibrillation and obtain sinus rhythm
Cardioversion
Defibrillation
Characteristics of ICD

- Volume $40 \text{ cm}^3$
- Mass $70 \text{ g}$
- Defibrillation energy $30 \text{ J}$
- Detection accuracy $90\%$
ICD Cross-section

BATTERY
CAPACITORS
Battery

- Small internal impedance – capacitors are charged by a current of 2-3 A
- Battery capacity equivalent to approx. 200 electric shocks
- or in time measures, approx. 9 years
Defibrillation High Voltage

- Battery voltage (3 V) is transformed to 750 V

High Voltage Capacitor

- Aluminium Electrolytic Capacitor
- Capacitor volume – approx. 30% of the ICD volume
Therapy

• Ventricular tachycardia
• Ventricular fibrillation
• Supraventricular arrhythmias

Implantation

• Local anesthesia
• Short postoperative care (1 day in hospital)
• 55,000 implantations per year (USA)
Therapies Provided by Today’s Dual-Chamber ICDs

- VT prevention
- Antitachycardia pacing
- Cardioversion
- Defibrillation

Atrium & Ventricle
- Bradycardia sensing
- Bradycardia pacing
Recent ICD Technologies: Integrated Atrial Therapies

**Atrium**
- Atrial tachyarrhythmia prevention
- Antitachycardia pacing
- Cardioversion

**Ventricle**
- VT prevention
- Antitachycardia pacing
- Cardioversion
- Defibrillation

**Atrium & Ventricle**
- Bradycardia sensing
- Bradycardia pacing
Intracardial ECG Signal Analysis

• Tachycardia diagnosis is based on:
  – PR interval analysis
  – HR analysis
Implantable leads and electrodes
Implantable leads and electrodes
1980

Large devices – Abdominal site

- First human implants
- Thoracotomy, multiple incisions
- General anesthesia
- Long hospital stays
- Complications from major surgery
- Perioperative mortality up to 9%
- Nonprogrammable therapy
- High-energy shock only
- Device longevity $\approx 1.5$ years
- Fewer than 1,000 implants/year
Small devices – Pectoral site

- First-line therapy for VT/VF patients
- Transvenous, single incision
- Local anaesthesia; conscious sedation
- Short hospital stays
- Few complications
- Perioperative mortality < 1%
- Programmable therapy options
- Single- or dual-chamber therapy
- Battery longevity up to 9 years
ICD Evolution
Programator
Programator

- Radio-frequency telemetry and programming
- Analysis of the signals
- Therapy
  - pacing
  - electrical shocks
- ICD performance testing
GUI of a Programator

![Image of a Programator GUI](image.png)
Conclusions

• Recent trials demonstrated that ICDs reduce SCD and overall mortality compared to AA drugs for VT/VF patients and a subset of high-risk, post-MI patients

• Rapid improvements in ICD technology have resulted in smaller devices, simplified implant procedures, improved device longevity, expanded therapy options and reduced implant costs

• Up to 54% of ICD patients could benefit from dual-chamber therapy (traditional pacemaker indications and other indications)
References: