The Automated Defibrillator: A Biomedical Engineering Success Story

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The Heart

- **A**
  - Aorta
- **VCS**
  - Superior Vena Cava
- **RA**
  - Right Atrium
- **RV**
  - Right Ventricle
- **LV**
  - Left Ventricle
Beating Heart: Video
Step 1: Electrical “Impulse”

- Heart Beats Triggered
  - Right Upper Chamber (Sino-Atrial Node)
  - Pacemaker tissue

- Electrical Impulse
  - Spreads through walls of Atria (top)
  - Causes Atria to contraction
Step 2: Valves Open

- Top chambers contract
  - Pressure keeps valves to lower chambers (ventr.) open
  - Lower chambers fill with blood
Step 3: Tiny Pause

- Electrical impulses build at atrioventricular node
  - Centre of Heart
  - Next wave of impulses leave as one
- Lower chamber continues to fill with blood
Step 4: Impulses Spread

- Impulses move along fibres in dividing wall of lower chamber (vent.)
- Impulses move down to base
- Then spread up along chamber walls
Step 5: Valves Shut & Open

- Contraction of lower chamber walls (vent.)
  - Pressure closes valves to top chambers
  - Opens valves to major blood vessels
    - Blood leaves heart
    - To Lungs (r. vent)
    - To Body (l. vent)
Heart Beating Video: Take 2
Heart Operation Explanation (Take 3)

Diagram of the Heart

http://en.wikipedia.org/wiki/Right_atrium
Cardiac Arrest Statistics

• In Canada, 35,000 to 45,000 people die of sudden cardiac arrest each year.

• For every one minute delay in defibrillation, the survival rate of a cardiac arrest victim decreases by 7 to 10%. After more than 12 minutes of ventricular fibrillation, the survival rate of adults is less than 5%.
Fibrillation, Defibrillation & Tachycardia

• Cardiac Arrhythmia
  – Abnormal activity

• Tachycardia
  – Fast heart rhythm that originates in one of the ventricles of the heart
  – Can lead to Fibrillation

• Fibrillation
  – Quivering with chaotic electrical impulses

• Defibrillation
  – Back to normal

Cardiac arrhythmia: Ventricular Fibrillation (V-Fib)
Automated Ext. Defibrillator: What is it & Why is it needed?

• Automated External Defibrillator
• Automatically diagnoses
  – cardiac arrhythmias of ventricular fibrillation and ventricular tachycardia
• Defibrillation Treatment
  – Electrical therapy
  – Stop arrhythmia,
  – Allowing the heart to reestablish an effective rhythm.
• Treat before ambulance arrives!
  – Increase rate of survival
  – Every second counts!
AED Technological “Game Changers”

• Insightful engineering is key
  – Understand the environment
  – Understand the user / operator
  – Understand the victim
  – Understand theory
  – Understand technology

• Three Main Changes
  1. Waveform
  2. Energy Storage & Delivery
  3. Ease of use
AEDs Around the World

Dulles Airport  
(Washington DC, USA)

Telephone cabin  
(Zurich, Switzerland)
The Scenario
Heart Attack at the Office

• Your coworker slumps over during a meeting
• You call 9-1-1
• Do you…
  – Wait for the paramedics?
  – Start CPR?
  – Get the AED?
Answer: All three!

• Get the AED!
  – It’s part of CPR
  – Chest compressions help blood flow but rarely restart heart

• Open & listen to instructions
  – Apply electrodes
  – Push button

• AED acts “automagically”!
  – Listens to heart
  – Applies shock when needed
What’s Going on Inside?

• Two main functions
  1. Recognize fibrillation
  2. Deliver 100 kW shock

• Decades of development
  – Reliable
  – Long shelf life
  – Safe
  – Easy to use
History of Electricity in Death & Therapy

- Edison vs. Tesla
  - DC vs. AC
  - Electric Chair
- Kouwenhoven & Knickerbocker (JHU)
  - GE-sponsored research
  - AC linesmen electrocutions
  - Electrocuted stray dogs
  - Noticed AC could sometimes revive dogs

William Kouwenhoven
Saved by a Spoon: First Human Defibrillation

• 1947: Beck (Cleveland)
  – 14-year old patient
  – Direct heart application

• Research Device
  – 110 VAC mains
  – Transformer (isolation)
  – Current limit resistor
  – Two table spoons
    • Wood handles

Early Defibrillator

Spoons!
DC Defibrillation in Europe & Russia

- 1890’s: Prevost & Batelli (Geneva)
  - Single DC Pulse Defib.
  - Capacitor charge
  - No need for AC mains
- Schtern (Russia)
  - Continued practice decades later
  - Arrested & later pardoned by Stalin

Modern Capacitors
More developments in Russia

- WWII: Gurvitch
  - Schtern’s student
  - DC defibrillation
  - Biphasic waveform
  - Big +ve, small -ve

- Lown (American)
  - Gurvitch schematics
  - Idea took off!
“Portable” Defibrillator

• 1965: First
  – 70 kg
  – Ambulance’s battery
  – Gas discharge relay
  – Inductor
  – Large paddles (grip)
Early Defibrillators, cont’d

• 2 operators required
  – Interpret EKG
  – Manipulate wires

• No safeguards
  – Cardiac victim?
  – Fainting spell?
  – Seizure?

• Room for error!
First Advance: Eliminate Bulky Paddles

- Metal-Chloride Gel
  - Better current transfer
  - 150 Ohms to 75 Ohms
- Flexible adhesive patches
  - Only one operator needed
Second Advance: Biphasic Waveforms

- Biphasic
  - Reduces power requirement
  - Reason not clear
  - Cell membrane role
- Smaller capacitors
- No inductor needed

**WAVE SCULPTING**: From the 1890s, experimenters defibrillated with some success. Naum Gurvitch waveform, however, became the bridge to the modern AED.
Switch to Semiconductors

- Peak voltage reduced
  - 4000 to 2000 V
- Remove Gas Relay
- Transistor-based
  - H-bridge
  - Like speaker & motor circuits
  - Microcontroller
    - Complex control!
Signal Processing

- Brain: Decisions...
  - Check connection
    - 30 kHz check signal
  - Check pulse
  - When to shock?
    - During T-wave
    - 100 ms
Signal Processing, cont’d

- Voltage averaging
  - No ground electrode
- Common-mode Rejection amplifier
- Heartbeat detector
  - Fibrillation is noisy!
  - This is hard!
- Ventricular Fib.?
  - >150 BPM
  - Therefore shock!

Measure heart rate… greater than 150 BPM?
Signal Processing, cont’d

- Atrial Fibrillation
  - Harder to detect
  - 3 measurements
  - Examine EKG derivative
  - Zero derivatives indicate atrial fibrillation 

Atrial Fibrillation? Measure 3 times
Simplified User Interface

- User under stress
  - No time for complexity
  - Single button interface
  - Device speaks

- Like a consumer device
The Future

• CPR
  – Weak link
  – Tiring
  – Less Mouth-to-mouth
  – Automated CPR?
References

• IEEE Spectrum Magazine
  – http://www.spectrum.ieee.org/nov08/6921

• Heart & Stroke Foundation
  – http://www.heartandstroke.ns.ca/site/c.inKMIPNIeIG/b.3668095/k.4D70/Automated_External_Defibrillator_AED.htm

• Wikipedia:
  – http://en.wikipedia.org/wiki/Myocardial_infarction

• History
  – “Life in the Balance” By Mickey S. Eisenberg
Further Reading/Viewing

- http://video.google.com/videoplay?docid=5701496219687599581#
- http://www.youtube.com/watch?v=WXwYYsi6z7Q