Cardiac Defibrillators
Need For A Defibrillator

- **Defibrillation** is the definitive treatment for the life-threatening cardiac arrhythmias *ventricular fibrillation* and pulseless *ventricular tachycardia*.

- Ventricular fibrillation results from:
  - Coronary occlusion
  - Electrical shock
  - Abnormalities of body chemistry

- This irregular contraction of the muscle fibers causes non effectively blood pumping and that results in a steep fall of cardiac output.
Ventricular Fibrillation

- **Ventricular fibrillation** can be converted into a more efficient rhythm by applying **high energy shock to the heart**.

- This causes all muscle fibers to contract simultaneously, which may then respond to normal physiological pacemaking pulses.

Restoration of normal rhythm in fibrillating heart as achieved by direct current shock (arrow) across the chest wall. The horizontal line after the shock shows that the cardiograph was blocked or disconnected for its protection during the period of shock.
Defibrillator

- Defibrillator is a device that delivers a therapeutic dose of electrical energy (electric shock) to the affected heart (fibrillated heart or other shockable rhythm) to force the heart to produce more normal cardiac rhythm.

- The shock can be delivered by means of electrodes placed on the chest of the patient (external defibrillation) or the electrodes may be held directly against the heart when the chest is open (internal defibrillation).

- *Higher voltage* are required for external defibrillation than internal defibrillation.
DC Defibrillator

- An energy storage capacitor is charged at a relatively slow rate from:
  - The AC line by means of a step-up transformer and rectifier arrangement or.
  - A battery and DC to DC converter arrangement
- During defibrillation the energy stored in the capacitor is then delivered (Discharged) at a relatively rapid rate (in order of milliseconds) to the chest of subject through the patient’s own resistance
- Energy level of defibrillators is from 2 to 400 Joules (J) (depends on the size of the patient and skin resistance)
- Required voltage in the range of 1000 to 6000 V (depend on the duration of the DC pulse)
- Current range is from 1 to 20 A
DC Defibrillator

- A variable auto-transformer $T_1$ forms the primary of
- A high voltage transformer $T_2$
- Rectifying the output of the transformer by a diode $D$ (half wave rectification)
- High voltage change-over switch 1, 2 (vacuum type)
- Oil-filed 16 micro-farad [$\mu$F] capacitor $C$
- $L$ current limiting inductor to protect the patient (disadvantage: own resistance → dissipation of a part of energy during the discharge process)
- The voltmeter $AC$ is to indicate the energy stored in $C$
DC Defibrillator

- $R_S$: limits the charging current to protect the circuit and determine the time for full charge on $C$ ($T=RC$)
- $R_L$: discharge resistance which the patient represents (50 to 100 $\Omega$)
- In position 1, the capacitor charges to a voltage $V_P$ set by the positioning of the autotransformer ($\approx 4000$ V)
- When the shock is to be delivered to the patient, a foot switch or a push button mounted on the handle of electrode is operated.
- After that the high voltage switch changes over to position 2 and the capacitor is discharged across the heart through the electrodes.
Energy Level of DC Defibrillator

- Energy level of a defibrillator can be controlling:
  - The voltage amplitude $V_P$ of the defibrillator by varying the setting on the varactor or
  - Duration of the defibrillator pulse

- The energy ($W_A$) stored in the capacitor $C$ and available for the defibrillation is:
  $$W_A = \frac{1}{2} CV^2$$
Lown waveform: *Curve 1* shows a typical discharge pulse of defibrillator which called “Lown” waveform.

- I rises rapidly to app. 20 A
- Then I decays to 0 with 5 ms
- A negative pulse is produced for 1 to 2 ms
- The pulse width defined as the time that elapses between the start of the impulse and the moment that the current intensity passes the zero line for the first time and changes direction (5 ms or 2.5 ms)

Current waveform $I(t)$ versus patient impedance $R_p$
Waveforms of DC Defibrillator

- Mono-phasic waveform: The delivered energy through the patient's chest is in a single direction
  - current flows in one direction from one electrode to the other
  - High level of energy
Bi-phasic waveform: The delivered energy through the patient's chest is in two direction.

- deliver current in two directions
- The Bi-phasic waveform reverses the direction of the electrical energy near the midpoint of the waveform
- Low-energy biphasic shocks may be as effective as higher-energy monophasic shocks
- Biphasic waveform defibrillation used in implantable cardioverter-defibrillators (ICDs) and automated external defibrillators (AEDs).
Defibrillator Electrodes

- The electrodes for external defibrillation are metal discs about 3-5 cm in diameter (or rectangular flat paddle 5x10 cm) and attached to highly insulated handles
  - Big size because of the large current, which is needed by the external defibrillation (avoiding of burning under the electrodes)
  - The size of electrodes plays an important part in determining the chest wall impedance, which influence the efficiency of defibrillation
  - Contain safety switches inside the housing
  - The capacitor is discharged only when the electrodes are making a good and firm contact with the chest of the patient
Defibrillator Electrodes

- For internal defibrillation when the chest is open, large spoon-shaped electrodes are used.
DC Defibrillator with Synchronizer

- Used for termination of ventricular tachycardia, atrial fibrillation and other arrhythmias
- There is a period in the heart cycle in which the danger is least and defibrillation must take place during this period (this is called cardio-version)
- In this device the ECG of the patient is fed to the defibrillator and the shock is given automatically at the right moment
- The function of the synchronizer circuit is to permit placement of discharge at the right point on the patient’s electrocardiogram (avoided during the $T$ wave and it is approximately $20 – 30$ ms after the peak of the $R$ wave)
DC Defibrillator with Synchronizer

- The synchronizer unit contains within it:
  - An ECG amplifier which receives the QRS complex
  - A time delay circuit which triggered by the QRS complex
  - The defibrillating capacitor is discharged after a desired delay time (app. 30 ms) across the chest through the electrodes

- The electrocardiogram of the patient is simultaneously monitored on a cardioscope

- The synchronizer unit produce a marker pulse at the moment the discharge takes place

Defibrillator/cardioverter block diagram
The comparator $A1$ turns the power supply on and off, depending on the voltages applied to its inputs.

After setting the energy level by mean $R3$

- Pressing the charge switch $\Rightarrow$
- Voltage on *terminal 1* ($V1$) = settled voltage (energy level) $\Rightarrow$
- Voltage on *terminal 2* ($V2$) = 0 $\Rightarrow$
- Comparator output = high $\Rightarrow$

- High voltage power supply is turned on $\Rightarrow$
- Charging the capacitor $C$ $\Rightarrow$
- Increase the voltage on terminal 2 until $V1=V2$ $\Rightarrow$
- Comparator output = low (0) $\Rightarrow$
- Stops the charge cycle
Manual defibrillator

- Manual defibrillator is a normal DC defibrillator where:
  - The clinician decide what charge (voltage) to use, based on their prior knowledge and experience, and will deliver the shock through paddles or pads on the patient's chest.
  - They require detailed medical knowledge
  - These unit are generally only found in hospitals and on some ambulances.
Automatic External Defibrillators (AEDs)

- A unit based on computer technology and designed to analyze the heart rhythm itself, and then advise whether a shock is required.
- It is designed to be used by lay persons, who require little training.
- It is usually limited in their interventions to delivering high joule shocks for $VF$ and $VT$ rhythms.
- The automatic units also take time (generally 10-20 seconds) to diagnose the rhythm, where a professional could diagnose and treat the condition far quicker with a manual unit.
- Automated external defibrillators are generally either held by trained personnel who will attend incidents, or are public access units which can be found in places including corporate and government offices, shopping centers, airports, restaurants, casinos, hotels, sports stadiums, schools and universities, community centers, fitness centers and health clubs.
Automatic External Defibrillators (AED$_S$)

- AED$_S$ require self-adhesive electrodes instead of hand-held paddles for the two following reasons:
  - The ECG signal acquired from self-adhesive electrodes usually contains less noise and has higher quality \(\Rightarrow\) allows faster and more accurate analysis of the ECG \(\Rightarrow\) better shock decisions
  - “Hands off” defibrillation is a safer procedure for the operator, especially if the operator has little or no training
Implantable Defibrillators (AID)

- Recommended for patients who are at high risk for ventricular fibrillation
- It constantly monitors the patient's heart rhythm, and automatically administers shocks for various life-threatening arrhythmias, according to the device's programming
- The capacitor within the device will be charged up to 750 V
- The heart represents a resistive load of 50 Ω
- The number of high energy shock is limited to 4 or 5 during any single arrhythmic episode
- The shock duration is approx. $4-8 \, \text{ms} \equiv 30-35 \, \text{J at 750 volts}$
Implantable Defibrillators (AID)

- AID systems have three main system components:
  - The defibrillator itself (AID): houses the power source, sensing, defibrillation, pacing, and telemetric communication system
  - The lead system: provides physical and electrical connection between the defibrillator and the heart tissue.
    - High energy pulse is delivered via a 6 cm × 9 cm electrodes pleased directly on the heart
    - Sensing is provided through leads screwed in the heart
The programmer recorder/monitor (PRM): An external device that provides a bidirectional communications link to an implanted AID and allows the physician to view status information and modify the function of the device as needed.

- This is via two coils, one is contained within the wand of the PRM and the second is contained within the implanted device.
- Battery: 3-6 V
- DC to DC converter: convert the 6 V to 750 V
- Capacitors are typically aluminum electrolytic because of the high volumetric efficiency and working voltage required (most two Cs in series)
- Load resistance is in the range of 20 – 50 Ω
- Peak current of the order of 40 A
An ICD is an electronic device that constantly monitors your heart rate and rhythm. When it detects a very fast, abnormal heart rhythm, it delivers energy to the heart muscle. This causes the heart to beat in a normal rhythm again.

It is used for:

- **Anti-tachycardia Pacing (ATP)** – When the heart beats too fast, a series of small electrical impulses are delivered to the heart muscle to restore a normal heart rate and rhythm.

- **Cardioversion** – A low energy shock is delivered at the same time as your heartbeat to restore a normal heart rhythm.

- **Defibrillation** – When the heart is beating dangerously fast, a high-energy shock is delivered to the heart muscle to restore a normal rhythm.

- **Bradycardia pacing** – When the heart beats too slow, small electrical impulses are sent to stimulate the heart muscle to maintain a suitable heart rate.
The ICD has in general two parts:

- **The Lead(s):** monitors the heart rhythm, delivers energy used for pacing, cardioversion and/or defibrillation.

- **The Pulse generator:** houses the battery and a tiny computer. Energy is stored in the battery until it is needed. The computer receives information from the leads to determine what rhythm is occurring.
It is composed of five battery-powered units:

- Sensing circuit
- High voltage converter
- Switching circuit
- Defibrillation control circuit
- Pacing control circuit

Block diagram of the automatic defibrillator