DEFIBRILLATORS

The two atria contract together and pump blood through the valves into the two ventricles, when the action potentials spread rapidly across the atria surface. After a critical time delay, the ventricular muscles are synchronously activated (contracted) to pump blood through the pulmonary and systemic circulatory systems.

During fibrillation, the normal synchronized rhythmic contractions of the atria or ventricles are replaced by rapid irregular twitching of the muscles. The fibrillation of atria and ventricles are called atrial and ventricular fibrillation respectively.

ATRIAL AND VENTRICULAR FIBRILLATION

Atrial fibrillation happens in young regular smokers. In atrial fibrillation, the ventricles function normally but there is non-synchronized stimulation from the atria. The ventricles respond with irregular rhythm to this non-synchronized stimulation from atria. Since most of the blood flows into the ventricles before atrial contraction, there is still blood for the ventricles to pump. Thus during atrial fibrillation, blood circulation is maintained but less efficiently. However, the sensation produced by fibrillating atria and irregular ventricular action is quite traumatic for the patient.

Ventricular fibrillation is the asynchronous contraction of heart muscles resulting from coronary occlusion, electric shock or abnormalities of the body chemistry. Because of this irregular contraction, the ventricles simply quiver rather than pumping the blood effectively. This results in steep fall of cardiac output and can prove fatal within a few minutes, if not corrected.

TYPES OF DEFIBRILLATORS

The ventricular fibrillation can be stopped by applying a high energy shock to the heart for a brief period. This causes all muscle fibers to contract (depolarize) simultaneously and then respond to normal pacing pulses. The instrument used for administering the shock is called defibrillator. This application of electrical shock to resynchronize the heart is called countershock.

80% of patients with sudden cardiac arrest are cured from if the treatment is given within one minute of the attack.

There are two types of defibrillators based on the electrodes placement.

External defibrillation/defibrillator:

In external defibrillation, the shock is delivered to the heart through electrodes placed on the chest of the patient. Paddle shaped electrodes with highly insulated handle is used. The shock voltage is 1000-6000V, contact impedance 100ohms with electrode gel, current passing through the heart is 10 – 60A, duration 1 – 5 milliseconds and excitation energy about 50 - 400J. Higher voltages are required for external defibrillation than internal defibrillation.

Internal defibrillation/defibrillator:

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In internal defibrillation, the electrodes are held directly against the heart when the chest is open. Large spoon shaped electrodes with insulated hand is used. The shock voltage is 50-1000V, contact impedance 50ohms, current passing through the heart is 1 – 20A, duration 2.5 – 5 milliseconds and excitation energy about 15 – 50J.

Depending on the nature of voltage applied, the defibrillators are divided into size types.

1. **AC defibrillation/defibrillator:**
   The ventricular fibrillation can be stopped by applying a high energy shock (6A at 60Hz ac) to the heart for a brief period (0.25 to 1 seconds). If the patient does not respond, the burst is repeated until defibrillation occurs. This method of countershock is known as **ac defibrillation**.
   AC defibrillator has a step-up transformer with various tapings on the secondary side for applying appropriate voltages for internal and external defibrillation.
   For external defibrillation 250 – 750V
   For internal defibrillation 60 – 250V

   An electronic timer circuit having RC network or monostable multivibrator circuit triggered by a foot switch or pushbutton switch, connects the output to the electrode for a preset time.

   **Disadvantages:**
   Repeated attempts are needed to correct ventricular fibrillation. It causes violet contraction of thoracic muscles and burning of skin under the electrodes. It cannot be used to correct atrial defibrillation because attempts to correct atrial fibrillation results in more serious ventricular fibrillation. Thus ac defibrillation is no longer used.

2. **DC defibrillation/defibrillator:**
   A capacitor is charged to a high dc voltage at a slow rate (in the order of seconds) and then rapidly (in the order of milliseconds) discharged through electrodes across the chest of the patient. The figure shows a typical dc defibrillator circuit.

   A variable autotransformer T1 forms the primary of a high voltage transformer T2. The output voltage of the transformer is rectified by a diode and is connected to a vacuum type high voltage changeover switch. In position A, an oil filled 16μF capacitor charges to a voltage set by the positioning of the autotransformer. When a foot switch or a pushbutton is mounted on the handle of the electrode is operated, the switch changes to the position B and the capacitor discharges across the heart through electrodes. The inductor slows down the discharge and thus eliminates a sharp undesirable current spike that occurs at the beginning of the discharge. The shape of the waveform depends on the value of capacitor and inductor.
   The capacitor discharges electrical energy between 100 and 400watts-sec or joules. The duration of the effective portion of the discharge is around 5 milliseconds. The discharge waveform indicating the current forced to flow through the thoracic cavity Vs time is shown below.
This type of waveform is known as **DC defibrillator discharge waveform (Lown or Monophasic)**. The area under the curve is proportional to the energy delivered. The peak value of current is nearly 20A and the wave is monophasic since most of its excursion is above the base line.

Even in DC defibrillation, myocardium and chest walls may be damaged because peak voltages up to 6000V may be used. To reduce this risk, some defibrillators produce dual-peak waveforms of lower voltage but longer duration (around 10mseconds). With this type of waveform, effective defibrillation is achieved with lower levels of energy (50-200 watt-seconds). The figure shows the **dual-peak monophasic defibrillator discharge waveform**. The defibrillators are called dual peak defibrillators (shown below) or delay line capacitive discharge dc defibrillators.

Effective defibrillation at lower voltages is also possible with **truncated defibrillator discharge waveform** shown below.

The amplitude of this waveform is relatively constant but its duration is varied to obtain the amount of energy required.

DC defibrillator is more successful in correcting ventricular fibrillation then the ac method. It can also be used for atrial fibrillation and other types of arrhythmias. It requires fewer repetitions and is less likely to harm the patients. DC fibrillator can be used for rapidly repeated shocks because it requires about 10s to recharge the capacitor.

**3. Synchronized DC defibrillator or DC fibrillator with synchronizer circuit:**

The process of using defibrillators to convert dangerous arrhythmias to one that is easily managed is called **cardioversion**. For e.g. to convert a tachycardia (fast heart) arrhythmia to normal rhythm. For this, anterior-posterior paddles are used. The defibrillation of atrial fibrillation may bring the ventricles into fibrillation. The defibrillation must take place in the period in the heart cycle, where the danger is least. This is also called cardioversion.

The countershock must not be delivered during the middle of the T wave which is called the heart’s vulnerable period because during this time, the heart is partially refractory and is susceptible to ventricular fibrillation. If the counter shock is provided during U wave, atrial fibrillation is produced. The optimum time for discharge is during or immediately after the downward slope of the R wave when the heart is in its absolute refractory period i.e. 20-30ms after the peak of R wave.
A simple DC defibrillator can be used for stopping ventricular fibrillation. But for termination of the atrial fibrillation, ventricular tachycardia and other arrhythmias, defibrillator with synchronizer circuit are used.

If the counter shock is provided during T and U wave, ventricular and atrial fibrillation are produced respectively.

**Defibrillator mode:**

QRS detector passes a signal if R wave is absent. The fibrillation detector gives an output signal if frequency components above 150Hz are found in the ECG signal. The defibrillation pulse is delivered only when if the two signals are received when the medical attendant energizes the switch.

**Cardioversion or synchronization mode:**

The ECG detector detects the peak of R wave. The defibrillation pulse is delivered after a delay of 30milliseconds from the occurrence of the R wave, to defibrillate atrium without inducing ventricular fibrillation.

The following figure shows the block diagram of the discharge control and recording circuitry of microprocessor based defibrillator monitor.

The operator selects the desired energy to the delivered. The microprocessor determines the corresponding value of stored energy based on the defibrillator internal resistance and the patient impedance, and regulates the stored capacitor voltage. The discharge current passes through a current-sensing transformer. The microprocessor determines the delivered energy based on the measured peak discharge current and the capacitor voltage.

**4. Square wave defibrillator:**

The capacitor is discharged through the patient by turning on a series SCR. A shunt SCR short circuits the capacitor and terminates the pulse when sufficient energy has been delivered to the patient.

**5. Double square pulse defibrillator:**

The conventional AC and DC defibrillators produce myocardial injury and diminished ventricular function for approximately 30 minutes after delivery of shock.

Here 8 – 60V double pulse with mean energy of 2.4 watt-second is applied. When the first pulse is delivered, some fibrillating cells are depolarized (defibrillated) and other cells which are in refractory state continued to fibrillate. The second pulse timing, pulse amplitude and width are selected such that the defibrillated cells are in refractory state and the cells which were refractory to the first pulse, are depolarized. Thus complete defibrillation is obtained by selecting proper pulse-space ratio.

Using double square pulse defibrillator, efficient and quick recovery of heart is achieved without any side effect like burning of myocardium or inducement of ventricular or atrial fibrillation.
6. Biphasic DC defibrillators:

It delivers DC pulses alternatively in opposite direction. **Biphasic waveform** delivers energy in both directions through the heart. Biphasic waveforms are more efficient and safer than monophasic waveforms. It is preferred because it can defibrillate more effectively than other waveforms, at lower energies.

7. Implantable defibrillators:

An implantable defibrillator continuously monitors a patient’s heart rhythm. If the device detects fibrillation, the capacitors are charged and discharged into the heart.

They consist of automatic implantable defibrillators (AID), lead system and programmer recorder/monitor (PRM).

The PRM is an external device providing bidirectional communication link to the AID, for getting real-time and stored ECG, battery status and other information relating to device function. The lead system provides physical and electrical connection between defibrillators and heart tissue. The AID houses power source, sensing, defibrillation, pacing and telemetric communication system. ROM provides non-volatile memory for system start-up task and some program space. RAM stores operating parameters and ECG. System control unit has telemetry interface and timers.

**ELECTRODES (PADDLES) USED IN DEFIBRILLATOR**

The large current discharges are applied through the skin, using electrodes called paddles. For **external (transthoracic)** use, a pair of metal disks of 8 to 10 cm diameter, with insulated hand is used. Conductive jelly or saline-soaked gauze pad is applied between each paddle surface and skin to prevent burning. The paddles must be applied with care so that the jelly does not accidentally form a conductive bridge between the paddles. If it does the defibrillation may not be successful.

The two electrodes applied may be anterior-anterior or anterior-posterior paddles. With **anterior-anterior paddles**, one paddle is placed on the heart and the other is placed on the left side of the patient’s chest, so that the current flow from bottom to the top of the heart. **Anterior-posterior paddles** are applied to patient’s chest wall and to the back so that the current flows from the back to the chest through the heart. This provides better control over arrhythmias due to atrial activity. The flat posterior paddle has a large diameter than the anterior paddle.

**Safety features:** To protect the person applying the electrodes from accidental electric shock, special insulated handles are provided on the paddles. A thumb switch on one or both the handles is used to discharge the defibrillator. This prevents the patient or someone else from receiving shock prematurely. A foot switch was used previously but not now because someone may accidentally step on the switch before the paddles are in place. In most modern defibrillators, the discharge occurs at the next occurrence of the R wave after the thumb switch is closed.

The electrodes have spring contact. The contacts close and defibrillator is fired only when these electrodes are adequately pressed on the thorax. This avoids the burns occurring due to poor electrical contact between electrodes and the skin are prevented.
For charging the defibrillator, a charge switch is located on the front panel of the unit. In a newer mode, the charge switch is located in the handle of one of its paddles. In other defibrillators, the charging begins automatically after discharge.

The **internal paddles** are applied directly to the myocardium (heart) during open-chest surgery. Such paddles are flat with diameter 5 to 10cm. Large spoon shaped electrodes with insulated hand is used. The energy levels required for defibrillation ranges from 10 – 50Wseconds. The internal paddles are gas-sterilized or autoclaved.

Special **pediatric paddles** are available with diameters ranging from 2 to 6cm.

Most defibrillators include watt-second (joules) meters to indicate the amount of energy stored in the capacitor prior to discharge. Some of the energy indicated in the meter, is dissipated as heat in components (mainly inductors) in the unit and in electrode-skin interface. Hence the patient receives less energy than the amount indicated on the meter. Hence for setting the amount of energy needed for various countershock procedures, a calibration chart is prepared. The defibrillators with dual peak monophasic and truncated waveforms, deliver energy equal to preset levels.

**Anterior paddle:**

**Posterior paddle:**

The posterior electrode is flat and is designed so that the patient can lie on it. Size ranges from 8 – 10cm.

**Precautions to be taken while using defibrillator along with implanted pacemakers:**

An implanted pacemaker pulse generator located immediately beneath a defibrillator paddle could be damaged during a discharge because of large amount of energy released in the body. The lump beneath the skin, due to the pacemaker, may reduce the effective skin contact area of paddle and increase the danger of burns. Thus care should be taken to avoid placement of a paddle over or near the pulse generator.

**Problems:**

1. Calculate the energy stored in a 16μF capacitor of a DC defibrillator, if voltage used is 6000V.
   \[ E = \frac{1}{2} CV^2 = 288 \text{Joules} \]

2. Calculate the energy stored in a 16μF capacitor of a DC defibrillator that is charged to a potential of 7000Vdc.
   \[ E = \frac{1}{2} CV^2 = 400 \text{Joules or Ws.} \]

3. Calculate the energy stored in a 16μF capacitor of a DC defibrillator that is charged to a potential of 5000Vdc.
   \[ E = \frac{1}{2} CV^2 \]