Chapter 15
Implantable Cardioverter Defibrillators

Abstract Implantable defibrillators represent the most significant innovation to thwart sudden cardiac death caused by ventricular arrhythmias. Devices have also been designed for the treatment of atrial fibrillation. ICDs are generally implanted in subjects who have withstood more than one incident of ventricular tachycardia or fibrillation. They are also applicable in subjects whose clinical synopsis indicates highly probable, up-and-coming persistent ventricular tachycardia or fibrillation. Chosen highly suggestive subjects with atrial fibrillation too can benefit from ICDs. In contrast to pacemakers, ICDs are endowed with capability of dispensing electrical shocks of high energy to the heart. These shocks are imparted to set right serious, life-threatening, rapid, and sustained arrhythmias. Ventricular fibrillation and ventricular tachycardia are such arrhythmias. Atrial fibrillation too has devastating effects. Such abnormalities are unmanageable by pacing with electrical pulses of low energies and are often irredeemable if not bothered about. The battery chemistry of ICDs uses silver vanadium pentoxide. Large and bulky capacitors are necessary to change the 3–6 V battery output into the 750 V shock required to defibrillate a heart.

Keywords ICD • Defibrillation • Sudden cardiac death • VT • VF • Cardioversion • Epicardial/edocardial/subcutaneous lead • Arrhythmia • Single-chamber/dual-chamber ICD

15.1 Introduction

The predicament of sudden cardiac death (SCD) is multifaceted having many aspects and requiring multipronged attack. Many questions have been posed concerning its physiopathological mechanisms. These inquiries at the convergence of physiology with pathology are still evading answer [1]. Very unexpectedly and unpredictably, patients ailing with congestive heart failure pass away owing to

© Springer International Publishing Switzerland 2016
V.K. Khanna, *Implantable Medical Electronics*,
DOI 10.1007/978-3-319-25448-7_15

arrhythmia leaving their beloved ones shocked and bewildered. This may happen even to patients undergoing confirmed beta-blockade medical therapies. Approaches developed specifically to prevent sudden death include treatment with amiodarone hydrochloride or shock delivery by an implantable cardioverter defibrillator (ICD). The competence of amiodarone to trim down death risk is uncertain and unresolved. Plain, shock-only ICD therapy provides better survival chances than afforded by modern drug therapy [2, 3].

A superfluity of medical researches has reinforced the benefits of ICD in clinical practice [4]. Implantable cardioverter defibrillator has metamorphosed the treatment of patients who stand at the risk of sudden cardiac death [5–7]. It is a small battery-powered, pager or a mini cassette-sized electronic device. Typically, it weighs approximately 85 g. It occupies 40 cm^3 volume. The location for its placement is underneath the skin in the chest of the patient. Surgery for ICD implantation is done under the influence of local anesthesia and sedation only.

The patients who are recommended ICD implant are primarily those facing the danger of sudden cardiac death (SCD). These are the patients suffering from cardiac ailments known as ventricular tachycardia or ventricular fibrillation. The term "ventricular tachycardia or VT" means rapid regular beating of the ventricles, the lower chambers in the heart. "Ventricular fibrillation or VF" implies rapid uneven pounding of the ventricles. It may be noted that the adjective "rapid" is common to both disease states, but in one case the heart beat is regular and faster than normal; in the other case, it is irregular and quicker than usual.

15.1.1 Explanation of VT and VF

VT is defined as three or greater than three ventricular extrasystoles in succession at a rate >120 bpm (beats per minute). Often, it may exceed 150 bpm. An extrasystole is a heartbeat outside the normal rhythm of the heart that occurs in response to an impulse from its natural pacemaker, the sinoatrial node. It is a premature contraction of the heart arising from some part of the heart other than this node. The extrasystole is followed by a stoppage or pause period. During this period, the electrical system of the heart resets itself. After the pause, the heart contracts with greater force. This forceful contraction of the heart is termed palpitation.

In VF, the ventricles contract in a much disorganized, ineffective fashion. Essentially, the heart ceases to pump. If untreated, survival is unlikely. VT is often diagnosed and treated. But, unfortunately, VF almost always results in cardiac arrest and death if not stopped quickly. This kind of death is known as "sudden cardiac death." VT frequently degenerates into VF if prompt remedial action is not initiated. Thus, VT and VF are two ghastly and frightening heart arrhythmias that cause the heart to beat very fast, either regularly or irregularly.

15.1.2 Cardioversion

ICD continuously monitors the rhythm of the heart. It inspects and invigilates the heart beat with great caution. Any abnormality is unable to escape its scrupulous attention. It quickly identifies any abnormal heart rhythm. No sooner than it detects a very fast, abnormal heart rhythm, it supplies an electrical shock immediately to restore a normal rhythm of the heart. However, when the heart is beating normally, the device remains calm and quiescent. It wakes up from its state of dormancy only when called upon to do so. Thus, the overall function of ICD is described as “cardioversion.” The term “cardioversion” implies the conversion of one cardiac rhythm to another. It is the transformation of an abnormal heartbeat into a normal heartbeat. In general, cardioversion implies the discharge of comparatively high-energy electrical shocks into or across cardiac tissue to apprehend a tachyarrhythmia of a heart chamber, i.e., a heart rate >100 bpm [8]. The term “cardioversion” is also applied to the cessation of high rate tachycardias using electrical pulses or bursts of lesser energy. Defibrillation is the halting of atrial or ventricular defibrillation by higher energy shocks. It has been considered in the past as a form of cardioversion. ICD systems provide synchronous cardioversion shocks and/or asynchronous defibrillation shocks. Another technique known as antitachycardia pacing (ATP) involves the application of petite spurts of pacing impulses at rates greater by a 0.1–0.2 factor than the tachycardia. It terminates the arrhythmia in 0.6–0.9 fractions of episodes. Then shocks are unnecessary. The quality of life of the patient is improved. Moreover, the battery life of ICD is lengthened.

15.2 Difference Between ICD and Pacemaker

It must be clarified that both ICDs and pacemakers considered here are implantable medical devices. Further, it must be recapped that they are both implanted under the skin of chest or abdomen of heart patients (Table 15.1). But ICD is capable of imparting a greatly effective bump to the heart if it starts to beat in a dangerous way. This may be looked upon as a grueling, punishing jolt to bring back the departure of heart beat to normalcy. The pacemaker uses only low-energy pulses to prompt the slow beating heart. These pulses can be viewed as attempts to cajole and coax the heart to function properly, not as severe impacts.

In the newer-generation ICDs, the capabilities of supplying high-energy shock as well as low-energy pacing pulses are provided in the same device. These ICDs operate in two modes. They have modes for defibrillation, wherein the device imparts a high-intensity shock to reinstate regular rhythm of heart. They also have facilities for pacemaker function, wherein the device conveys a minute electrical incitement to the heart at predetermined rates.

With progress in underlying technologies, ICD sizes have continuously decreased. These defibrillators are made in considerably shrunken versions. Consequently, the

Table 15.1 Comparison between pacemaker and ICD

Sl. No.	Pacemaker	ICD
1.	It is recommended in patients, whose heartbeat slows down to an unwholesome low rate, beating too leisurely	It is counseled in unambiguous patients who are at jeopardy for possibly grave ventricular arrhythmias
2.	Its appearance is similar to ICD, but it is smaller in size than ICD	It looks much alike a pacemaker, except that it is a little bigger in size. Colloquially or informally, it is the pacemaker's big brother
3.	It is implanted for treatment of less dangerous heart rhythms. These arrhythmias usually occur in the atria, the upper two chambers of the heart. It boosts up the slow heartbeats to standard level by supplying low-energy electrical pulses to restore normal heartbeat, i.e., to maintain the heart thumping at the appropriate rate	It treats fast, dangerous heartbeats because of a frightening rhythm disorder from the ventricles, the two bottom chambers of the heart. The ventricles start to quiver rather than contract strongly. Initially, it sends pulses of low energy to reestablish heart rhythm, but switches to pulses of higher energy when the low-energy shocks are unsuccessful in preventing death from a cardiac arrest
4.	The low-energy pulses delivered by it do not produce any pain. They are faint and painless	Although lasting for only a fraction of a second, the high-energy pulses supplied by it are painful to the patient
5.	It is not shocking the heart all the time. It only imparts feeble prompting signals to the heart muscle	It shocks the heart whenever it needs to be shocked
6.	It is a device producing a mild action	It is a device causing an aggressive action

miniaturized defibrillators are almost always implanted in the pectoral area rather than in the abdomen, as they used to be done earlier. This is highly convenient and opportune for the patient. It has also lowered implant morbidity. Long-term lead-related complications have also faded away and disappeared.

15.3 Necessity of ICD

Questions that come to the mind of the reader are: What is the problem if the defibrillation shocks are delivered from outside? Why is it necessary to implant the defibrillator inside the body? Of course, the defibrillation shocks can be given externally but it is a matter of how soon they are provided in order to be effective. A patient may suffer from ventricular fibrillation, a rapid and disorganized activation of the ventricles in the heart, while in home, in office, on the road, or anywhere, and help to deal with medical emergency may take time to reach the patient. But this disease does not forgive any deferments. It must be stated that despite the progress in exigency medical systems and expertise of resuscitation techniques, sudden cardiac death almost always follows ventricular fibrillation [9]. Survival rates are very low for persons who have cardiac arrest outside the hospital [10]. Even the patients who recover after resuscitation may writhe with severe, lasting weakening of cognitive and motor functions. This happens due to holdups that are often incurred before restoration of a steady rhythm. Therefore, an implantable device is essential to keep an eye on and interpret cardiac rhythm like a robot and to provide necessary shocks for defibrillation within no time after detection of ventricular fibrillation. Consequently, the implantable cardioverter defibrillator has matured from a therapy of last opportunity for patients suffering from frequent cardiac arrest to a standard for management of arrhythmias. This standard is useful in crucial prevention of a life-threatening event occurring for the first time. It is also used in secondary prevention cases. It is a tool preventing the repetition of a likely lethal arrhythmia or cardiac arrest in patients who have a history of coronary heart disease.

Patients who can potentially be benefitted from an ICD are separated into two broad categories [11]:

(a) Secondary prevention: In this category are the patients who have endured a dangerous ventricular arrhythmia. Also reckoned are the patients who have sustained ventricular tachycardia (VT). For these patients, the ICD is implanted for the secondary avoidance of sudden cardiac arrest. Sustained VT is usually defined as VT instigating hemodynamic symptoms, chiefly fainting, prefainting, or chest pain prolonging for more than 30 s.
(b) Primary prevention: This category consists of patients who have hitherto not suffered sudden cardiac arrest, albeit stand at high risk for the same. In this case, an ICD is implanted for prevention of this mishap as a primary facility.

15.4 Historical Background

Drs. Michel Mirowski and Morton Mower and their coworkers were distraught and gloomed by the death of a close associate and advisor. The mentoring colleague had been admitted to the hospital with complaints of persistent ventricular tachyarrhythmias. Stricken by this grief, they spearheaded the development of a life-prevention device in the late 1960s [12]. A novel idea evoked from their disenchantment with the capabilities of the treatments at hand during those times for individuals poised at high death risk. They conceptualized an implantable device. This device would incessantly watch the heart rhythm and provide corrective action in the event of any deviation of the rhythm from its course. For the correction procedure, the device would be embellished with the ability to transport shocks for defibrillation whenever ventricular tachyarrhythmias occurred. In the decade 1970–1980, many tentative, investigational models were fabricated and improved by these workers. After years of vigorous testing and evaluation, the first implantation was accomplished in 1980 in a young woman agonized with recurrent ventricular fibrillation. This woman had experienced two preceding cardiac arrests. Several years elapsed and the ICD treatment was offered in only a few centers. It was mainly aimed at persons with recognized cardiac arrest due to ventricular fibrillation. Commercial defibrillation devices were approved by the US Food and Drug Administration in 1985. Expertise of these devices grew by leaps and bounds and so did validation of the usefulness of defibrillators to terminate malignant ventricular arrhythmias. Since that time, ICDs have become the preferred treatment for patients at high danger from terrifying arrhythmias. This is attributed to rapid refinements and sophistications in device technology. Stockpiling of support from randomized medical assessments also helped the enterprise. Loss of confidence in the universal efficacy of drug therapy further promoted the adoption of ICDs. From the treatment of last resort, ICDs have advanced as an embodiment of supreme standard therapy for patients at high threat for ventricular tachyarrhythmias. High-risk patients are those who have endured life-threatening arrhythmias. They include persons with heart diseases who are in fear of such arrhythmias, but have not shown any symptoms.

15.5 ICD Construction

Broadly, the implantable defibrillator consists of two main components: (a) the pulse generator and (b) one or more leads for pacemaker function and electrodes for defibrillation. The pulse generator is housed in a sealed titanium can. This pulse generator can is the abode of electronic circuitry and power supply. It contains microprocessors and associated integrated circuitry for signal filtering/analysis of the cardiac rhythm and the delivery of pacing pulse or shock. Memory chips inside the can are used to store electrograms and patient data. A module is included for telemetry through bidirectional transmission of information. The can encloses a Li–Ag–V_2O_5 battery with DC–DC voltage converters for power conditioning. It also contains aluminum or aluminum chloride electrolytic capacitors to store charges. On the top cover of the pulse generator can lies a header made of epoxy resin. Leads for pacing and defibrillation leads are connected here. The leads must be capable of transferring shocks of high energy to the heart without any damage to the myocardium.

15.6 Epicardial versus Endocardial (Transvenous) Lead Systems

Early defibrillators used epicardial patches, but transvenous leads are now more commonplace (Table 15.2).

Figure 15.1 shows epicardial ICD and Fig. 15.2 depicts endocardial ICD.

Another ICD category is subcutaneous ICD (Fig. 15.3). In subcutaneous ICD implantation [13], the lead is stationed in the tissue of the chest underneath the skin. Its orientation is in the vertical direction. It is kept parallel to and at a distance 1–2 cm to the left sternal midline. Horizontally, its position is at the level of the sixth rib, until reaching the left anterior axillary line. The lead carries an 8-cm shock

Table 15.2 Epicardial and endocardial leads

Sl. No.	Epicardial leads	Endocardial leads
1.	They offer superior distribution of the defibrillating electric field	Their field distribution is inferior
2.	They need less energy for defibrillation	They need greater energy for defibrillation. For adequate defibrillation, separate shocking components were often demanded. Examples are superior vena cava and coronary sinus leads. Besides, subcutaneous patches or arrays are also used. These weaknesses have been largely overcome by advancement in two areas. First area is lead design. Another area pertains to waveforms used for defibrillation
3.	They require a thoracotomy for inserting the device. Thoracotomy is a risky surgical procedure	They have avoided the need for thoracotomy. They provide demoted implant morbidity, along with improved long-term lead reliability

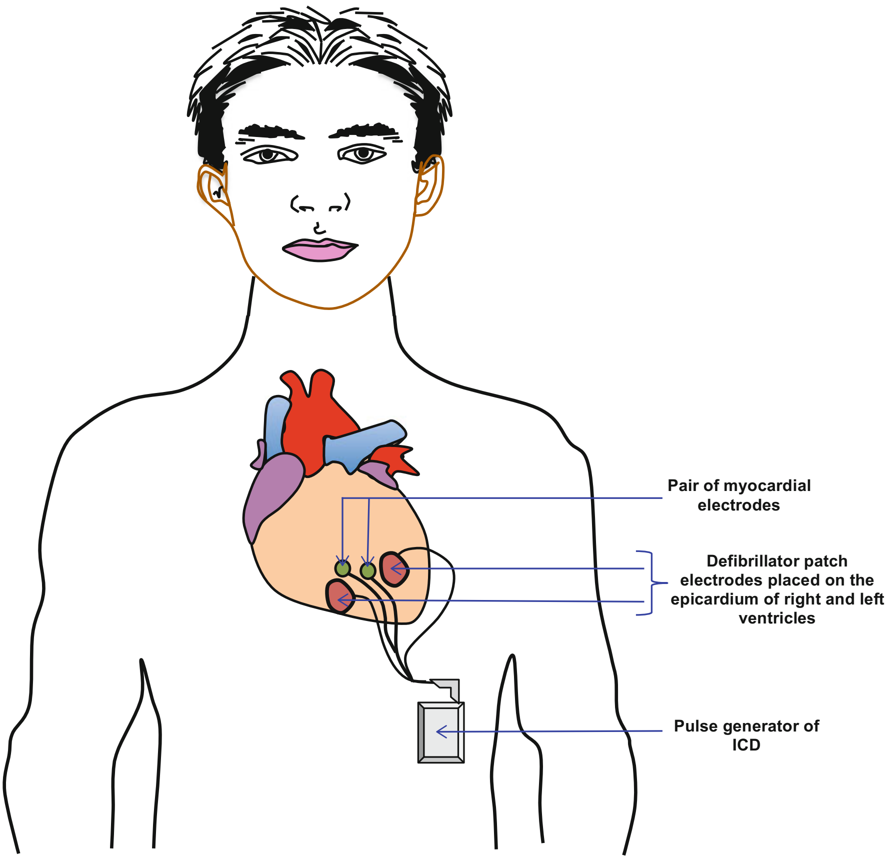

Fig. 15.1 Epicardial ICD implantation

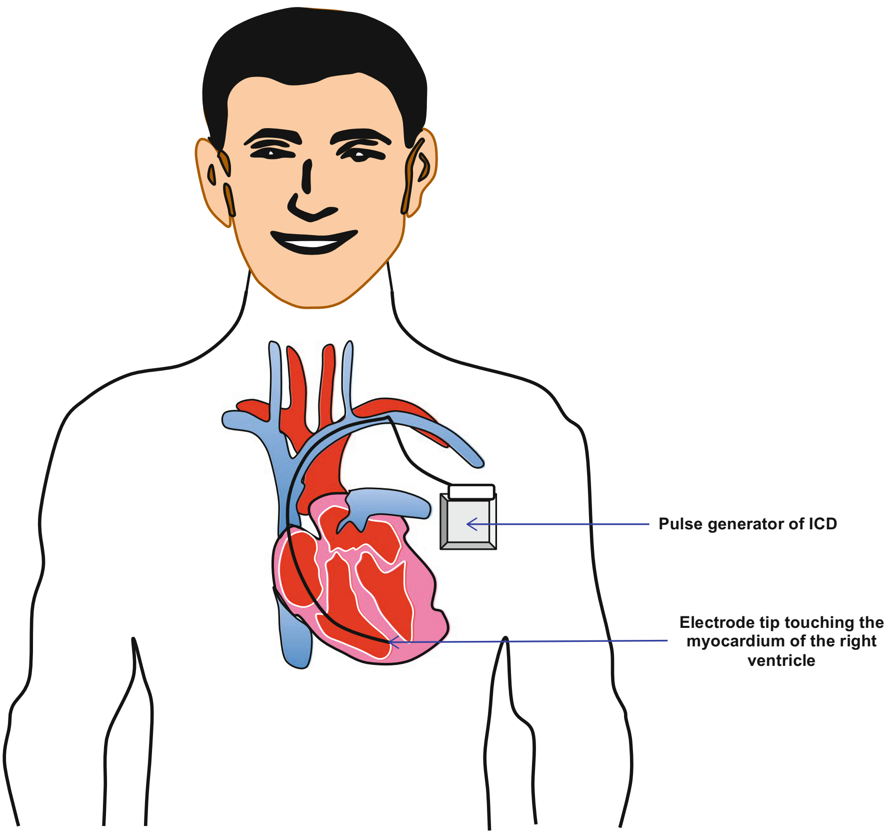

Fig. 15.2 Endocardial (transvenous) ICD implantation

coil. The coil is surrounded by two sensing electrodes. The pulse generator is twice the size of the traditional type. It is placed in the tissue of the chest beneath the layers of the skin. Its location is above the sixth rib flanked by the left midaxillary and the left anterior axillary lines.

15.7 Arrhythmia Detection

The obvious question at this stage is: What is the sure sign of the occurrence of a ventricular arrhythmia for which a heavy shock is urgently required. Otherwise, there are chances of false alarms and unnecessary wasteful shocks leading to great discomfort of the patient. To this intent, two rhythm characteristics are widely used for detection of a ventricular arrhythmia. One characteristic is heart rate; the other is duration of arrhythmia, typically 1–3 s. These characteristics can be programmed according to the requirements of the individual patient. The rate indicator makes a

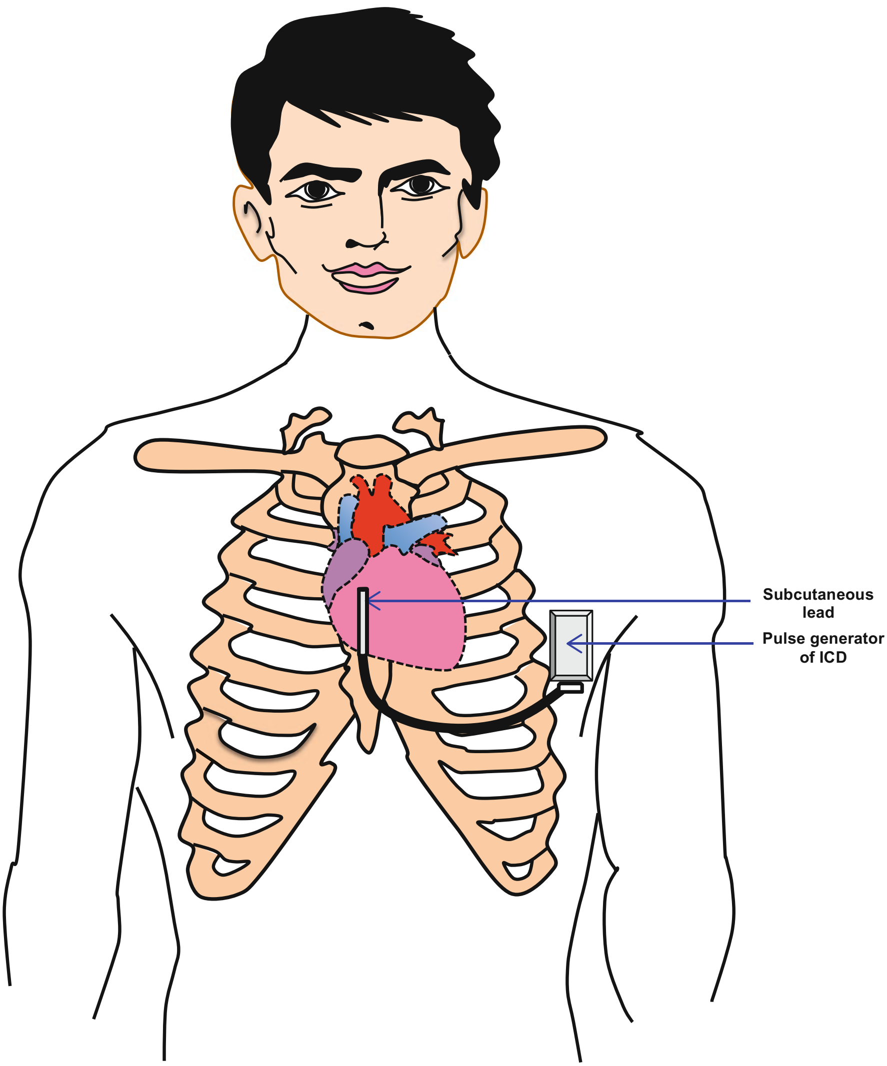

Fig. 15.3 Subcutaneous ICD implantation

distinction between a tachyarrhythmia and a normal cardiac rhythm. The duration criterion enables the revealing of continuous incidents only.

During ventricular fibrillation, the bipolar electrogram has small amplitude or its amplitude is unstable. For detection of such low-amplitude signals, a specially designed method called the dynamic sensing technique is employed. In this technique, the ICD allows sensitivity-gain adjustment. It transforms the amplitude of the intracardiac signal in the range which the device can detect during the full cardiac cycle. By employing this dynamic gain or sensitivity threshold, QRS detection becomes permissible. After QRS detection, the sensitivity is decreased. Immediately, it begins to decrease to the value that was programmed. Hence, T-wave counting is eschewed while consenting to extremely responsive detection during a major part of the cardiac cycle. Thus the recognition of a ventricular fibrillation event is facilitated.

15.8 Detection Zones

ICDs offer several detection zones that are classified on the basis of the seriousness of arrhythmias. Independently programmable treatments are ascribed to each zone. The swift tachycardias, e.g., ventricular fibrillation, are accorded the highest priority of attention. They are treated more aggressively. An immediate shock is the only retort. The slower ventricular tachycardias are retaliated with overdrive pacing which is not painful. Frequently, the requirement for a shock is eliminated. By further division of the ventricular tachycardia region into low speed and high speed, dissimilar treatments are applied to ventricular tachycardias of dissimilar speeds. Thus, ICDs deal with various kinds of malfunctions in different ways. Obviously, a high-intensity shock is not necessarily the cure for all disorders. It may be superfluous on some occasions.

15.9 Algorithms for Detection of Arrhythmias

Distinguishing between different types of arrhythmias is possible by step-by-step enunciation of the procedure to be followed in reading the patterns of ECG signals. For solving this problem, ICDs use various algorithms which continuously work on the ECG signals to classify whether a certain characteristic of ECG waveform represents a benevolent or a dangerous situation. These algorithms depend on the type of ICD, whether single or dual chamber. The former uses information from its single lead, whereas the later operates on information supplied by both the leads. The algorithms and computer programs aid in arriving at the correct decision regarding the degree of threat to the patient.

Algorithms also vary among devices, depending on the manufacturer. However, they share some general trends, which will be discussed here.

15.9.1 Algorithms for Single-Chamber ICDs

To discriminate whether the arrhythmia is ventricular or supraventricular, a single-chamber ICD uses enhancements. These are based on rhythms of cardiac patterns or QRS waveform, its shape, and its structure. Features unique to an arrhythmia are carefully scrutinized in identifying its outbreak. It is beneficial to find whether the onslaught of arrhythmia was gradual or sudden, whether the arrhythmia cycle was stable or unstable, or whether the intracardiac QRS width was normal or unduly long.

Unanticipated and astonishing outburst of arrhythmia aids to tell apart the episode of a ventricular tachycardia from that of sinus tachycardia. A ventricular tachycardia has a fast start, while sinus tachycardia is marked by a slow beginning.

Constancy of the length of arrhythmia cycle is a vital characteristic which assists in separating the regular ventricular tachycardia from the usually irregular atrial fibrillation. For demarcating between different QRS wave morphologies, a comparison is performed between the intracardiac electrogram of the QRS complex in tachyarrhythmia with the form and structure of QRS for the patient during normal sinus rhythm. Resemblance of the two electrograms supports the development of a rapid supraventricular tachycardia. Divergence between electrograms is an alert for ventricular tachycardia.

The intracardiac QRS width is a parameter which is used to extricate ventricular from supraventricular tachycardias. In case of a broad QRS complex tachycardia, there is a definite probability of ventricular tachycardia.

15.9.2 Algorithms for Dual-Chamber ICDs

As already said, detection algorithms for tachyarrhythmia ICDs exploit the information obtained concomitantly from the two leads: the atrial lead and the ventricular lead. During atrioventricular dissociation, the atria and ventricles are not activated synchronously. This condition forewarns of ventricular tachycardia if the ventricular rate is >the atrial rate. Atrioventricular association indicates the existence of a supraventricular rhythm. If fibrillation has been recognized in the atria, a jagged, uneven ventricular rhythm can only be assigned to atrial fibrillation.

15.10 Therapies Administered

There are three principal ways to terminate *ventricular arrhythmias*. These are by delivering synchronized shock (cardioversion), by imparting non-synchronized shocks (defibrillation), or by overdriving (antitachycardia pacing).

Tachyarrhythmias within the scope of ventricular fibrillation are dealt with by furnishing instant defibrillation. *Ventricular tachycardias* are treated by supplying concatenation of overdrive pacing. This is especially true for the slower types. As a repercussion to failure of overdrive pacing, cardioversion is done at low energies. However, circumstances may arise wherein the rhythm worsens or proves to be unmanageable by employing less forceful steps. In the aftermath, defibrillation is imperative.

Ventricular fibrillation or fast speed ventricular tachycardia requires defibrillation. In ventricular fibrillation, the efficacy of defibrillation is >98 %.

For stopping *ventricular tachycardias* that are not controlled by overdrive pacing, low-energy cardioversion is frequently a solution. Many monomorphic tachycardias (in which all the QRS waves look the same) are brought to a halt with shocks of 1 J or less. Because arrhythmias are sometimes hastened by low-energy shocks, low-energy cardioversion should at all times be succeeded by high-energy shocks.

In existing devices, facility for administration of 4–8 consecutive shocks is available. Maximum energies of the shocks imparted lie in the range 25–42 J. Using endocardial leads with biphasic waveforms, this energy is adequate to defibrillate the mainstream of patients. Actually, the average energy required for victorious defibrillation is ~10 J. To ensure accomplishment, a methodical testing of the system is done during implantation. Induced fibrillation must be quickly replicated by an energy that is a minimum 10 J less than the utmost output of the device. Defibrillation should be reproduced with the standard 10 J safety allowance. If it is not obtained, suitable changes are indispensable and have to be carried out. The lead configuration may be altered. The electrodes may be repositioned. More defibrillating elements may be added. However, this is hardly ever the case with biphasic waveforms.

15.11 Postimplantation Patient Follow-Up and Monitoring

For postimplantation look-after and well-being of the ICD-receiving patient, the patient is required to report for outpatient visits at regular intervals. These visits are generally scheduled after every one month. In some cases, patients are called every three months. During these visits, the doctor examines whether there were any variations in rhythmic patterns of heart signals during the reporting period. If they happened, he/she studies the details of type of rhythmic disturbances that actually occurred. He/she also looks at the adequacy/redundancy of necessary electrical shocks that were delivered, whenever they were called for. It is important to know whether these shocks were actually useful or prodigally given? On the whole, the doctor evaluates the effectiveness of the treatment provided and tries to find whether the measures taken are sufficient. Depending on these inputs, the doctor makes suitable amendments/modifications in the programmed parameters to obtain the correct settings.

The above patient monitoring is performed in a noninvasive fashion. For this purpose, a programming wand is applied over the chest region of the patient. Application of the wand establishes wireless messaging from the ICD with a computer which is externally located. Information flow in both directions between the ICD and computer enables the monitoring.

During patient checkups, the battery condition is always determined. When the battery energy diminishes to a preset level, ICD replacement is compulsory. No chances of insufficient power to energize the ICD are allowed for dealing with any cardiac emergency.

The patients with ICDs have to adhere strictly to many restrictions in lifestyle as instructed to them by their doctors. Such patients are prohibited from undergoing MRI procedures. However, they are allowed to undertake X-ray scanning. Doorways of stores fitted with electronic theft detection devices should be avoided. The patients should not stand close to them. Nor they should stand in the vicinity of airport security chambers. Holding magnetic items next to their unit is forbidden. Stereo speakers are a common example of such items. Also, they should never hold cellular telephones against the device. Some ICD patients may be advised to avoid situations or tasks in which they or someone else could be injured in case they suffer from dizziness or happen to lose consciousness. On a case-by-case basis, sports requiring tiresome exercises such as diving, piloting, athletics, or similar activities may be allowed on a limited format. It is likely that even after ICD implantation, antiarrhythmic drugs may be prescribed to some patients.

Among the adverse effects of implantation may be mentioned the risks of infection at the implant site. The device may be visible from outside as a lump below the skin. So, cosmetic concerns arise. In addition, psychological apprehension and discomfort of electric shocks always persist. Multiple shocks may pose challenging medical and psychological management issues. These issues may be troublesome for the attending healthcare providers [14–16]. ICD-related suspicions and reservations, e.g., unnecessary worry, are the most familiar signs shown by ICD beneficiaries [17]. Patients must be imparted supplementary education and knowledge about further care after discharging from hospital [18]. At some places, support groups have been formed. In these groups, the ICD patients can share and discuss their problems with medical experts. These discussions allay many vague and imaginary fears which haunt the patients.

15.12 Discussion and Conclusions

An ICD prolongs life in patients who have either experienced or are prone to serious abnormal heart rhythms, often resulting from a damaged heart [19, 20]. The ICD is superior to conventional pharmacological therapy and has established its supremacy over medicines. There are several strong forecasters of death in ICD patients. Some of these are the age of the patient, renal dysfunction, and chronic obstructive pulmonary disease. Diabetes and peripheral vascular disease make the situation more murky [21]. The older age group is less active from physical standpoint. They are less pleased with its physical operation. They also show a little more fretfulness than their younger counterparts [22]. Among the aged patients, ICD intervention may not be found to be economical. It may not prove to be worth its cost. But the procedure may become cost-effective in those patients who are likely to live for >5–7 years after implantation [23, 24]. Widespread use of ICDs for primary prevention will encumber and burden the financial blueprint of several healthcare systems. This is because of the prohibitively high price of each ICD device. Further, a sizable population of patients is potentially eligible to receive ICDs [25]. Over and above, there are extensive variations in implantation rates for ICDs. The main reason is that a common or uniform policy for sudden death prevention is not laid down. Even in a terrestrial region where the broad-spectrum level of healthcare is progressive and well esteemed by the people, gross variability in implant rates is encountered [26, 27].

Review Exercises

15.1 Differentiate between ventricular tachycardia and ventricular fibrillation. Which is more likely to lead to death if not treated immediately?

15.2 What is meant by cardioversion? How is it achieved? What is defibrillation? How does antitachycardia pacing differ from the above two modalities?

15.3 How does a defibrillator differ from a pacemaker? Which device caters to the need of a more life-threatening situation? Will a pacemaker help in such a circumstance?

15.4 What motivated Drs. Michel Mirowski and Morton Mower towards the development of a device that will keep a vigil on heart's activity and deliver a high-voltage shock in cardiac emergency. Describe the early phase of defibrillator progress.

15.5 Name the two main components of a defibrillator? Explain their functions. What is the name of the material from which the outer case of a defibrillator is made? What kind of battery is used in the defibrillator?

15.6 Which of the two kinds of leads, epicardial or transvenous, gives better electric field distribution? Which one needs less energy for defibrillation? Which one is implanted by thoracotomy?

15.7 Is the same kind of treatment always applicable to ventricular tachycardias of different rates? If not, what are the different possibilities?

15.8 What rhythm characteristics are used to detect ventricular arrhythmias? What is dynamic sensing? Why is it necessary? How is it done?

15.9 How does a single-chamber ICD differentiate among different arrhythmias? What kind of information is furnished by dual-chamber detection algorithms?

15.10 Describe the three ways to manage ventricular arrhythmias and the manner of their application under different conditions of the heart.

References

1. Hu K (2006) Prevention of sudden cardiac death. Internist (Berl) 47(10):1040–1049
2. Kadish A, Dyer A, Daubert JP et al (2004) Prophylactic defibrillator implantation in patients with nonischemic dilated cardiomyopathy. N Engl J Med 350:2151–2158
3. Bardy GH, Lee KL, Mark DB et al (2005) Amiodarone or an implantable cardioverter–defibrillator for congestive heart failure. N Engl J Med 352(3):225–237
4. Ghislandi S, Torbica A, Boriani G (2013) Assessing the outcomes of implantable cardioverter defibrillator treatment in a real world setting: results from hospital record data. BMC Health Serv Res 13:100–109
5. Josephson M, Wellens HJ (2004) Implantable defibrillators and sudden cardiac death. Circulation 109(22):2685–2691
6. Masoudi FA, Go AS, Magid DJ et al (2012) Longitudinal study of implantable cardioverter-defibrillators: methods and clinical characteristics of patients receiving implantable cardio-

verter defibrillators for primary prevention in contemporary practice. Circ Cardiovasc Qual Outcomes 5(6):e78–e85
7. Russo AM (2014) Are we improving care of medicare patients undergoing primary prevention implantable cardioverter-defibrillator implantation? Circulation 130(10):808–810
8. Plombon WJ, Stroebel JC (2003) Implantable Cardioverter/Defibrillator. US 20030004552A1, 15 p
9. Huikuri HV, Castellanos A, Myerburg RJ (2001) Sudden death due to cardiac arrhythmias. N Engl J Med 345:1473–1482
10. DiMarco JP (2003) Implantable cardioverter–defibrillators. N Engl J Med 349(19):1836–1847
11. Deyell MW, Tung S, Ignaszewski A (2010) The implantable cardioverter-defibrillator: from Mirowski to its current use. B C Med J 52(5):248–253
12. Glikson M, Friedman PA (2001) The implantable cardioverter defibrillator. Lancet 357:1107–1117
13. De Maria E, Olaru A, Cappelli S (2015) The entirely subcutaneous defibrillator (s-icd): state of the art and selection of the ideal candidate. Curr Cardiol Rev 11(2):180–186
14. Sears SF Jr, Conti JB (2003) Understanding implantable cardioverter defibrillator shocks and storms: medical and psychosocial considerations for research and clinical care. Clin Cardiol 26(3):107–111
15. Stutts LA, Cross NJ, Conti JB et al (2007) Examination of research trends on patient factors in patients with implantable cardioverter defibrillators. Clin Cardiol 30:64–68
16. Sears SF, Matchett M, Conti JB (2009) Effective management of ICD patient psychosocial issues and patient critical events. J Cardiovasc Electrophysiol 20(11):1297–1304
17. Camm J, Sears SF Jr, Todaro JF et al (1999) Examining the psychosocial impact of implantable cardioverter defibrillators: a literature review. Clin Cardiol 22(7):481–489
18. Palacios-Ceña D, Losa-Iglesias ME, Alvarez-López C et al (2011) Patients, intimate partners and family experiences of implantable cardioverter defibrillators: qualitative systematic review. J Adv Nurs 67(12):2537–2550
19. Reiffel JA, Dizon J (2002) The implantable cardioverter-defibrillator: patient perspective. Circulation 105:1022–1024
20. Birnie DH, Sambell C, Johansen H et al (2007) Use of implantable cardioverter defibrillators in Canadian and US survivors of out-of-hospital cardiac arrest. Can Med Assoc J 177:41–46
21. Alba AC, Braga J, Gewarges M et al (2013) Predictors of mortality in patients with an implantable cardiac defibrillator: a systematic review and meta-analysis. Can J Cardiol 29(12):1729–1740
22. Hamilton GA, Carroll DL (2004) The effects of age on quality of life in implantable cardioverter defibrillator recipients. J Clin Nurs 13:194–200
23. Barra S, Providência R, Paiva L et al (2015) Implantable cardioverter-defibrillators in the elderly: rationale and specific age-related considerations. Eur J Pacing Arrhythm Card Electrophysiol 7(2):174–186
24. Groeneveld PW, Farmer SA, Suh JJ (2008) Outcomes and costs of implantable cardioverter-defibrillators for primary prevention of sudden cardiac death among the elderly. Hear Rhythm 5(5):646–653
25. Hlatky MA, Mark DB (2007) The high cost of implantable defibrillators. Eur Heart J 28(4):388–391
26. Boriani G, Berti E, Biffi M et al (2010) Implantable electrical devices for prevention of sudden cardiac death: data on implant rates from a 'real world' regional registry. Eur J Pacing Arrhythm Card Electrophysiol 12(9):1224–1230
27. Lubinski A, Bissinger A, Boersma L et al (2011) Determinants of geographic variations in implantation of cardiac defibrillators in the European Society of Cardiology member countries—data from the European Heart Rhythm Association White Book. Eur J Pacing Arrhythm Card Electrophysiol 13(5):654–662