An introduction to the automatic implantable cardioverter-defibrillator and its anesthetic implications

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This paper presents a description of the automatic implantable cardioverter-defibrillator (AICD), as well as information pertaining to indications for its use, patient selection criteria, surgical implantation techniques, and anesthetic implications. A brief historical overview of the development of the AICD is included. Complications, indications, and contraindications associated with the device are discussed.

Key words: Implantable cardioverter, implantable defibrillator.

Introduction
Sudden cardiac death accounts for an estimated 450,000 deaths in the United States each year, 80% of which are attributed to ventricular tachycardia (VT) or ventricular fibrillation (VF). Survivors of primary VT and/or VF are growing at an amazing rate because of the widespread availability of paramedic teams, advances in emergency medicine, and the increased number of laypersons capable of administering cardiopulmonary resuscitation. Patients at risk for sudden cardiac death are also being identified earlier. All these advances have led to a growing population that may require antiarrhythmic intervention.

Currently, pharmacotherapy is the first modality of treatment utilized to prevent lethal dysrhythmias from recurring. However, such medical treatment is successful in only 30-40% of these patients. Other treatment modalities for recurrent VT and VF include removing or destroying the reentrant site by surgical resection, electrical ablation, or cryoablation. However, these techniques are limited because of high failure rates. Antitachycardia pacemakers have been approved for treatment of supraventricular dysrhythmias but are still in the testing stage for treating VT. More recently, implantable electronic devices have gained considerable attention in controlling life-threatening tachyarrhythmias.

Today, there are several devices available that offer a variety of programmable features, such as pacing, internal memory, programmability, and telemetry. As of January 1992, the Cardiac Pacemakers, Inc. (CPI) Ventak Models 1550® and 1600® were the only two devices in the United States that were approved for treatment of ventricular dysrhythmias by the Food and Drug Administration (FDA). However, there are several other devices in the investigational stage that incorporate antitachycardia overdrive pacing, bradycardia pacing, cardioversion, and defibrillation. This paper will focus on the currently available automatic implantable cardioverter-defibrillator (AICD) offered by CPI.

History of the AICD
The AICD has been used in human beings for more than 10 years, and its utilization has increased dramatically each year (Figure 1). The crucial breakthrough in the development of AICDs was the discovery that epicardial energy requirements for...
defibrillation are much less than are those for trans-thoracic defibrillation. These low-energy impulses effectively terminate VF, since only a "critical portion" of the ventricular myocardium must receive the defibrillating shock. This low-energy requirement makes the concept of small implantable devices feasible.

Implantation of the first automatic defibrillator was performed in 1980 by Dr. Michael Mirowski at the Johns Hopkins Hospital in Baltimore, Maryland. After witnessing the sudden cardiac death of a close friend, Dr. Mirowski devoted his time and energy to the development of a defibrillating device that could automatically sense lethal dysrhythmias and deliver a shock to eradicate the disorganized rhythm. The earliest models were designed solely to sense and correct VF. Newer models are more capable of distinguishing between supraventricular and ventricular tachycardias in addition to VF. In 1985, the AICD received FDA approval and, to date, more than 18,000 patients have received AICDs.

Definition of the AICD

Essentially, the AICD is a miniature cardioverter-defibrillator that consists of a pulse generator and a set of leads that attaches directly to the heart. The pulse generator weighs approximately 197 g and measures 11 x 7 x 2 cm. Two electrodes deliver the defibrillating shock to the heart. One electrode is usually a transvenous catheter situated in the superior vena cava, and the other electrode is a flexible patch that covers the apex of the heart. A separate set of electrodes senses heart rate and serves for R wave synchronization during device discharge.

The earliest models of automatic implantable defibrillators utilized the transvenous electrode and the apical patch to sense both QRS morphology and heart rate, as well as defibrillation. However, this arrangement of leads resulted in large P wave amplitude which interfered with the detection of dysrhythmias. Today, a multitude of individualized lead-and-patch configurations based on intra-operative electrophysiology studies are utilized. Some patients may require two or more patches for adequate cardioversion or defibrillation, because of increased myocardial mass or antiarrhythmic drug therapy.

Currently, the standard defibrillation lead system consists of a coil electrode positioned in the right atrium through the superior vena cava and a patch electrode that is placed over the apex of the left ventricle. Alternatively, two patch electrodes placed anteriorly and posteriorly on the left and right ventricles can also be used. The rate-monitoring pair of electrodes can be either a transvenous endocardial electrode positioned at the apex of the right ventricle or epicardial screw-in leads placed 1 cm apart on the left ventricle. The pulse generator is situated in a subcutaneous pocket in the left lower abdominal area anterior to the abdominal fascia below the waistline.

The AICD continuously monitors and analyzes the patient’s heart rate and electrocardiographic waveform. When specific criteria are identified, the device initiates the capacitor-charging cycle. Presently, two different parameters are analyzed to determine the presence of a lethal dysrhythmia: (1) the heart rate and (2) the probability density function (PDF). The rate that initiates cardioversion is programmed for each individual and is usually set not to fire unless the rate exceeds 155-175 beats per minute.

The PDF is a reflection of the amount of time that ventricular signals spend on the isoelectric line during the cardiac cycle. For example, during sinus rhythm, most of the ventricular signal is at the isoelectric line, whereas during VF, very little time is spent on the baseline. The PDF was designed to discriminate benign tachycardias from malignant tachyarrhythmias, but to date it has demonstrated only limited success in improving the performance of this task. Its usefulness in this regard remains a controversial issue.

The AICD is capable of analyzing both PDF
and heart rate changes and delivering a defibril-
atory shock within 15-20 seconds of the onset of fi-
brillation. In addition to rate programmability, the
Ventak devices also permit energy programmabil-
ity. The first shock can be programmed to deliver
between .1 J and 30 J, and the second through fifth
shocks are fixed at 30 J.

The AICD also measures dysrhythmia-sensing
times, capacitor charge times, and keeps track of the
number of clinical and test shocks delivered. If a
dysrhythmia has not been terminated by a cycle of
five shocks, then the device must detect 35 seconds
of a rhythm other than VT/VF in order to resume
normal monitoring operation. In this instance, ex-
ternal defibrillation is necessary. It is important to
emphasize that newer models are capable of render-
ing several different programmable algorithms to
treat persistent tachyarrhythmias, utilizing the
least aggressive therapy first.

For example, if VT is detected, the device may
first try overdrive pacing. If that is unsuccessful,
low-energy cardioversion at predetermined energy
levels may be delivered, followed by defibrillation
at predetermined energy levels for persistent dys-
rhythmias. As stated earlier, these advanced de-
vices are still in the investigational stage. The ex-
pected life of the device currently used is either 4-5
years or a total of 300 discharges.3, 6, 7, 10, 11

**Patient selection criteria**

The increasing success rate of the AICD is, in
part, the result of the fact that patient selection
criteria have been well defined. Patients who pres-
ent for an AICD must have survived one episode of
cardiac arrest resulting from a ventricular tachy-
arrhythmia not associated with an acute myocardial
infarction or have experienced recurrent VT des-
pite conventional drug therapy. Other considera-
tions include a life expectancy of at least 6 months,
emotional maturity and stability, stable residency,
and a willingness to cooperate with follow-up care.
It is also important to note that patients who have
several episodes of dysrhythmias each day are not
suitable candidates for AICDs, since repeated de-
vice discharge could result in psychological impairment and premature battery depletion. \(^9\,10\,12\)

**Anesthetic implications**

Obviously, patients with a history of lethal dysrhythmias present a challenge to the anesthesia team. Therefore, a thorough preoperative evaluation is imperative. Tests indicated include a coronary arteriogram, left ventriculogram, electrophysiology studies, pulmonary function tests, and treadmill exercise testing. \(^9\) Electrophysiology studies are used to determine the inducibility of ventricular dysrhythmias and the characteristics of those induced. The maximum heart rates attained with treadmill testing and spontaneous and induced VT are compared, and the cutoff rate for the AICD is determined. \(^1\,10\)

Techniques for implanting the AICD depend on the underlying cardiac pathology, the history of previous surgeries, and whether corrective open-heart procedures are contemplated.

There are three surgical approaches for the insertion of the AICD: the subxiphoid, median sternotomy, and left lateral thoracotomy. Exposure of the cardiac apex is necessary for placement; therefore, a general anesthetic is required for all approaches. If other types of cardiac surgery are being performed, then the median sternotomy approach is used, and all procedures are completed at once. \(^1\,10\,12\)
The left lateral thoracotomy approach is used when the patient has already had a sternotomy or when AICD implantation is the only procedure being performed. It provides excellent exposure and avoids the scar tissue interference associated with the previous sternotomy.

The subxiphoid approach is limited to use with patients in whom a concomitant open-heart procedure is not indicated. Although this approach requires a less drastic incision, it offers limited surgical exposure and makes manipulation of patches difficult.

With both the left lateral thoracotomy and subxiphoid approaches, the right ventricle and superior vena cava endocardial leads are usually placed transvenously under fluoroscopy through the left subclavian or left internal jugular vein. Therefore, it is important to introduce any transvenous pacemaker wires or Swan-Ganz catheters from the right side of the body if these surgical approaches are to be used. A double-lumen endotracheal tube may also be used to deflate the left lung in order to provide better exposure of the myocardium during the left lateral thoracotomy approach.

Intra-arterial and central venous pressure monitoring is established prior to induction of general anesthesia, and some form of cardiac pacing — either external or transvenous — must be available. Antiarrhythmic drug therapy is generally discontinued prior to surgery in order to avoid any myocardial depression and to facilitate intraoperative electrophysiologic testing. Intraoperative antidysrhythmic drugs are reserved for immediately life-threatening situations.

Serum electrolyte levels must be maintained as close to normal as possible in order to avoid any dysrhythmias which could be triggered by electrolyte imbalances. In addition, every effort to maintain a normal body temperature should be implemented to avoid defibrillation threshold changes caused by hypothermia.

Electrophysiology studies are performed routinely before, during, and after the AICD has been implanted to ensure that spontaneous or induced tachyarrhythmias meet the AICD-sensing parameters and that the AICD can terminate the dysrhythmias. The goal of intraoperative electrophysiology studies is to determine the defibrillation threshold, which is defined as the least energy that reproducibly defibrillates the heart 15 seconds after induction of VF. The AICD devices available today have a maximum energy output of 30 J. A defibrillation threshold of less than 20 J is desirable and is usually achieved by manipulation of the patch positions.

Because volatile anesthetic agents may alter the defibrillation energy requirements, it is preferable to use intravenous agents instead. In studying dogs, Wang and Dorian compared defibrillation energy requirements when a variety of different anesthetic agents were used and found that fentanyl resulted in lower defibrillation energy requirements than did enflurane or pentobarbital anesthesia.

Pacemakers, temporary or permanent, potentially can interfere with the AICD’s functioning. Unipolar pacemakers can alter sensing capabilities during tachycardia and can cause signals of lesser amplitude to go unrecognized. The pacer spikes may continue to be counted by the AICD, and a VT/VF may not be terminated. Therefore, because of “double counting,” use of unipolar pacemakers is contraindicated, and a patient with such a pacemaker should have it replaced prior to AICD implantation.

Another potential problem in patients with pacemakers is that of lead dislodgement, which could falsely elevate the heart rate sensed by the AICD. Pacemaker generators should be placed at a site distant from the AICD generator, since most newer pacemakers have permanent magnets in the programming wand that could convert the AICD to the inactive mode.

Activation and deactivation of the AICD are accomplished by placing a ring magnet over the right upper quadrant of the device. An audible tone occurs with proper placement of the magnet. A constant tone indicates the inactive mode, and a beeping tone synchronous with the sensed R wave indicates the active mode. Contact with any electromagnetic field is contraindicated; therefore, magnetic resonance imaging is not recommended. Exposure of a patient to a magnetic field for longer than 30 seconds may inactivate the AICD.

Electrocautery, which is frequently used in many surgical procedures, is another common source of interference. AICD discharge during the use of cautery has been reported. The grounding pad should be placed as far from the generator and leads as possible, and a ring magnet should be readily available if it becomes necessary to inactivate the device. It is recommended that the device be implanted in the deactivated mode and that it be temporarily deactivated during all electrocautery.

**Complications**

As medical technology continues to improve, the complications and risks associated with the AICD will also continue to diminish, both in number and in magnitude. However, because of the major surgery that is required for the device’s installation, surgical complications pose formidable
risks; namely, infection, intraoperative death, bleeding, and lead dislodgement. The overall surgical mortality rate for patients with a left ventricular ejection fraction of about 35% is less than 3%. Malfunction of the device itself also poses a risk to the patient. Oversensing as a result of fractured or malpositioned electrodes, T wave sensing, or unipolar pacemakers can lead to premature discharge of the device. Conversely, it has also been reported that appropriate dysrhythmias have failed to activate the AICD, a situation known as undersensing.

Conclusion

Despite major advances in antiarrhythmic drug therapy, cardiac surgery, and community-based emergency medical systems, sudden cardiac death remains a major public health problem. The AICD has proven to be a valuable therapeutic adjunct for patients at risk for sudden cardiac death. It is clear that the benefits of AICD implantation for selected patients far outweigh the risks. The AICD has an acceptably low rate of complications and has been clinically proven to increase survival rates of patients with life-threatening dysrhythmias.

As the number of AICD implants continues to increase, so too will the number of healthcare professionals who must care for these high-risk patients. The AICD is a highly effective treatment modality that offers hope of prolonged survival to patients with life-threatening ventricular dysrhythmias.

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