Perioperative Management of the Patient with an Implantable Cardioverter Defibrillator

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Patients suffering from arrhythmic, ischemic, or dilated cardiomyopathy are particularly exposed to the risk of sudden death from ventricular fibrillation [1–3]. In 2015 [2], guidelines for the indications of ICD implantation were update from 2005 [2], in the light of the publication of two large studies [2, 3]. In this context, early defibrillation by electric shock offers the best chance of survival [2–5]. With over 500,000 sudden deaths a year in the North American continent alone, the number of cardiac defibrillators implanted has increased exponentially since 2005, especially after publication of different studies and meta-analyses showing the benefit of this treatment in terms of survival [5–7]. Thus 270,000 defibrillators were implanted worldwide in the year 2005 alone, of which 30% were in the USA.

In addition, these figures are in perpetual progression with more than 100,000 implantations per year in the USA [1]. Consequently the anesthesiologist encounters these patients more and more frequently in his practice. In this context, it would appear crucial for the physician to understand how this device works and to know how to prevent and treat perioperative dysfunctional complications.

6.1 Principal Characteristics and Modes of Function of Implantable Cardioverter Defibrillators (ICD)

ICD is a device detecting episodes of life-threatening arrhythmias such as ventricular tachycardia or ventricular fibrillation by means of specific intracardiac leads. Once detected, these arrhythmias can be interrupted immediately. In the case of a

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ventricular tachycardia, the ICD delivers a high-frequency stimulation corresponding to the "overdrive pacing" functionality. In the case of ventricular fibrillation, the ICD delivers an internal electric shock corresponding to the "cardioversion" functionality. The first ICD was developed by Dr. Michel Mirowski in the 1980s while working at NASA. The device was implanted in association with a pacemaker and necessitated a thoracotomy for placement of the epicardial electrodes with the generator being implanted in the abdominal cavity for reasons of size. Present-day technology has allowed miniaturization of the ICD permitting subpectoral implantation of devices measuring only 3.5 cm^2 and 1.2 cm wide. The most sophisticated devices may combine double or triple intracardiac leads to associate defibrillator, pacemaker and cardiac resynchronization therapy.

ICD leads are inserted into the right heart chambers via the superior vena cava. For a single-chamber device, the lead tip is positioned in the right ventricle. For a dual-chamber device, the additional tip is positioned in the right atrium. In the case of resynchronization therapy, the third lead is introduced into the coronary sinus and onward to the left ventricle leading to simultaneous pacing of the right and left ventricles. The device is powered by a small voltage battery amplified by a transformer which allows delivery of a 30–36 J shock. Modern devices also provide overdrive pacing to electrically convert a sustained ventricular tachycardia and a pacemaker function for backup pacing in case of bradycardia. The pulse generator acts as the cathode for the defibrillation, the shock being delivered from the right ventricular lead, called "coil," toward the generator in order to place the ventricles in the middle of the electric field for an effective cardioversion. The ICD is also able to detect and analyze arrhythmias, storing this information in the device for analysis. Modern ICD has multiple programmable features, but essentially it measures each cardiac R-R interval and categorizes the rate as normal, too fast (short R-R interval), or too slow. When the device detects a sufficient number of short R-R intervals within a period of time, it will declare a tachycardia episode. The internal computer will decide between antitachycardia pacing and shock based on its programmed algorithm. The defibrillator is programmed to detect different types of malignant arrhythmias according to the heart rate and the morphology of the QRS whose characteristics will have previously been defined for each individual patient. Thus the cardiac electrophysiologist will establish frequency intervals specific to each patient defining a ventricular tachycardia or ventricular fibrillation. The appearance of an episode of arrhythmia corresponding to one of these threshold zones previously determined will lead to the appropriate response of the ICD. Thus the highest frequencies correspond to the ventricular fibrillation threshold which will activate the cardioversion function triggering a shock of up to 36 J. In the case of a ventricular tachycardia of a lower frequency corresponding to the threshold previously defined for a ventricular tachycardia, the anti-tachyarrhythmia function will be activated. This activation will result in the delivery of a series of trigger impulses at a high synchronized frequency with the object of pacing the heart at a higher rate than the intrinsic arrhythmia in order to force the conduction network into a refractory period, thus blocking the spontaneous arrhythmia. In the majority of case, this therapy is painless, well tolerated, and often successful and thus can be considered to be

Table 6.1 Generic defibrillator code

1st letter	2nd letter	3rd letter	4th letter
Shock chamber	Antitachycardia pacing chamber	Tachycardia detection	Antibradycardia acing pacing chamber
O: none A: atrium V: ventricle D: dual (A + V)	O: none A: atrium V: ventricle D: dual (A + V)	E: electrocardiogram H: hemodynamic	O: none A: atrium V: ventricle D: dual (A + V)

an important therapeutic progress. In the case where this mode is unsuccessful, an internal shock can be delivered. However, when the rate of a sinus tachycardia or a supraventricular arrhythmia overlaps the zone calibrated for ventricular rate, the risk of provoking the anti-tachyarrhythmia function or even an electric shock exists. To avoid this problem, the majority of modern ICDs can be programmed to increase the diagnostic specificity notably by considering the widening of the QRS. This does not totally solve the problem for the supraventricular tachycardia with a bundle branch bloc, a consideration which the cardiac electrophysiologist must take into account when programming. Thus the modern 3rd and 4th ICD generations have been shown to be effective in 98% of episodes of arrhythmias [8].

Finally, the anti-bradycardia function is available on all recent ICD and consists of a pacemaker able to compensate a bradycardia or an asystole post-defibrillation. It may consist of simple ventricular pacemaker, but a dual- or even triple-chamber pacemaker is possible especially when a ventricular resynchronization is required.

Like pacemakers, ICDs have a generic code to indicate lead placement and function (Table 6.1).

When venous access is difficult, subcutaneous defibrillator may be helpful [2]. An electrode system is placed entirely subcutaneously, outside the thoracic cavity. A distal electrode on the defibrillator lead is associated to a proximal electrode located 8 cm from the tip of the lead. A coil is located between the tip and proximal electrode for defibrillation. The distal part of the lead is located at the left parasternal edge, and the device is placed over the fifth intercostal space between the left anterior and mid-axillary line. The device is capable of defibrillating with an output of 80 J [2]. Limits of this device are patients who require bradycardia pacing >30 s, antitachycardia pacing, or patients needing cardiac resynchronization therapy [2].

6.2 Intraoperative Dysfunction

The most frequent source of ICD dysfunction in the intraoperative period is electromagnetic interference (EMI) stemming from electric devices such as monopolar electrocautery or electric shaving occurring in proximity to the ICD generator. Radiofrequency waves between 0 and 10^9 Hz can generate EMI and thus cause ICD or pacemaker malfunction. Figure 6.1 summarizes the most frequent sources of EMI encountered during the intraoperative period. In contrast, X-rays, infrared, or

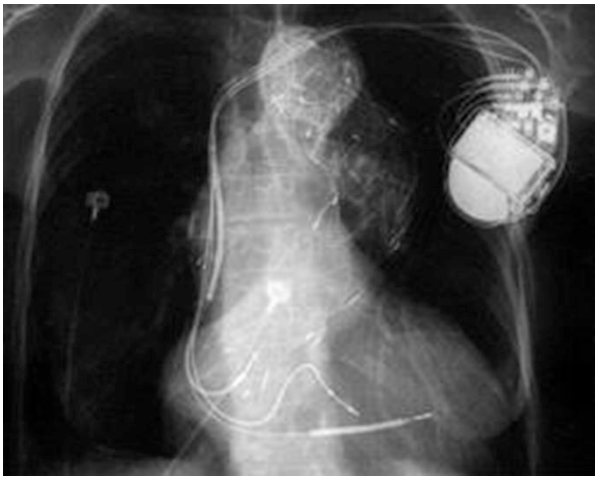

Fig. 6.1 ICD associated with a dual-chamber pacemaker

ultraviolet does not interfere with ICD..; In the specific case of radiotherapy, repeated exposures can damage the electric circuits in the generator but do not produce EMI of itself [5]. Thus, despite progress for enhancing protection against EMI risk, ICD remains still highly sensitive to interference in the intraoperative period. The manufacturers now incorporate filters and circuit shields that insulate the internal components. Moreover, for pacemakers, a shift toward bipolar leads (since 2000), which minimize the physical distance of the circuit with the anode and cathode incorporated in the lead tip, reduces the potential for EMI.

In contrast, the EMI risk is still high in ICD as the anode (lead tip) and cathode (generator) remain inevitably separated. During the intraoperative period, EMI can lead to the activation of the anti-tachyarrhythmia function and/or to delivery of an

Table 6.2 Most frequent sources of EMI with ICD during the intraoperative period

Sources of EMI with ICD during intraoperative period
• Electrocautery (monopolar > > bipolar)
• Nerve stimulators
• Evoked potential monitors
• Fasciculations (succinylcholine)
• Electric shaving
• High tidal volumes
• Radiofrequency ablation
• Magnetic resonance imaging
• External defibrillation
• Lithotripsy
• Electroconvulsive therapy

inappropriate electric shock. Total or partial inhibition of the pacemaker may occur, leading to cardiac arrest if the patient is pacemaker dependent (Table 6.2).

6.3 Indications and Benefits of ICD

The ICD has proven its efficiency in preventing sudden death: both in primary prevention, as in the case of sudden death post-myocardial infarction or consecutive to a nonischemic dilated cardiomyopathy, and in secondary prevention, for patients having already presented episodes of malignant arrhythmias [2–5].

6.3.1 Primary Prevention of Sudden Cardiac Death

In 2006 [4], update in 2015 [2], guidelines for the indications of ICD implantation were update from 2006, in the light of the publication of two large studies MADITII [9] and DINAMIT [10] in addition to one meta-analysis [11] considering all the ten studies published in the domain: MADIT I [12], CABG-Patch, MUSTT [13], MADIT II [9], CAT [14], AMIOVIRT [15], COMPANION [16], DEFINITE [17], SCD-HeFT [18], and DINAMIT [10].

A complete analysis of these data has allowed to define the indications for these devices [2–5]. Thus the patients who reaped the biggest benefit from the ICD in primary prevention are those who present a chronic left ventricular dysfunction at distance from an acute myocardial infarction or those within the context of a nonischemic dilated cardiomyopathy. Only four studies did not demonstrate the beneficial character of the ICD. The aforementioned studies, however [10, 14, 15], were carried out on a limited number of patients (CAT [14] and AMIOVIRT [15]) or in a context of recent myocardial infarction (between the 6th and the 40th day for DINAMIT [10]) or concerned implantations following coronary bypass surgery (CABG-Patch), a treatment which decreases considerably the relative risk of sudden death in the control groups.

On the other hand, the MADIT I [12] study carried out on a group of 196 patients in a context of ischemic heart disease and prior infarct with a left ventricular ejection fraction ≤35% highlighted a reduction in the annual mortality of 54% compared to the control group [12]. Coming from the same team, the MADIT II study concerning a larger sample size of 1232 patients, in a context of ischemic heart disorder with left ventricular ejection fraction ≤30% estimated at least 1 month after an infarct, reinforced these results with a reduction in annual mortality of 31% compared to the control group [9]. The MUSTT study, regarding a group of 704 patients, showed a reduction in mortality of 51% in the patients implanted in comparison to the control group which consisted of coronary patients for whom a ventricular hyper excitability could be medically treated without resort to a ICD [13]. The study COMPANION, concerning 1520 patients with ejection fraction ≤35%, 59% of whom were coronary, confirmed the advantage of the ICD with a reduction of 36% in the annual mortality when it was associated with a biventricular pacemaker compared to the patients

treated medically or by a biventricular resynchronization only [17]. Regarding the group with nonischemic dilated cardiomyopathy and a left ventricular ejection fraction ≤35%, the DEFINITE study concluded a decrease in the annual mortality of 35% [17]. The largest sample size came from the SCD-HeFT study with 2521 cases with cardiac insufficiency and a left ventricular ejection fraction ≤35% of ischemic etiology for 52% of the cases [18]. In this study, the reduction in the annual mortality with regard to the control group was 23%.

Finally, a meta-analysis which ensues from the analysis of these ten randomized studies concluded a relative reduction of 25% and an absolute reduction of 7.9% in the global mortality on a 2- to 4-year follow-up of the patients with a ICD [11].

In consequence, the recommendations concerning the implantation of ICD in primary prevention of sudden cardiac death put forward are: [2–5]

- The coronary patient with or without symptoms of cardiac insufficiency (NYHA II or III) with a left ventricular ejection fraction ≤30% estimated at least 40 days after an IDM and 3 months after surgical revascularization or angioplasty
- The coronary patient with left ventricular dysfunction (LVEF ≤35%) estimated at least 40 days after an infarct and 3 months after surgical revascularization or angioplasty presenting a triggerable ventricular arrhythmia (VT or VF)
- The patient presenting a seemingly primitive dilated heart disorder with left ventricular dysfunction (LVEF ≤30%) and symptomatic (NYHA II or III)
- The patients with documented ventricular fibrillation or hemodynamically not tolerated ventricular tachycardia in the absence of reversible causes or within 48 h after myocardial infarction who are receiving chronic optimal medical therapy and have a reasonable expectation of survival with a good functional status >1 year
- The patient with hypertrophic cardiomyopathy with an estimated 5-year risk of sudden death ≥6% and a life expectancy >1 year following detailed clinical assessment that takes into account the lifelong risk of complications and the impact of an ICD on lifestyle, socioeconomic status, and psychological health
- Cardiac amyloidosis, restrictive cardiomyopathy, and genetic disease at high risk of sudden death by ventricular fibrillation without any other known effective treatment

In patients with cardiac failure who remains symptomatic (NYHA III or IV) under optimal medical treatment, with left ventricular dysfunction (LVEF ≤35%) and duration of the QRS >120 ms, a biventricular pacemaker is recommended in association with the ICD for cardiac resynchronization.

6.3.2 Secondary Prevention of Sudden Cardiac Death

Secondary prevention by the ICD allowed a 27% reduction in the global mortality of the patients concerned [19]. Moreover, in the AVID study relating to 1016 patients having presented a cardiac arrest during a ventricular tachycardia or fibrillation, the

ICD resulted in a decrease in mortality, respectively, of 39, 27, and 31% at 12, 24, and 36 months, in comparison to the control group treated by amiodarone alone [20]. In the CIDS study, including 658 cardiac arrest survivors due to a ventricular tachycardia or fibrillation, the ICD tended to decrease, in a not significant way, the relative risk of mortality of 33% after 5 years in comparison to the control group benefiting from an anti-arrhythmic treatment by amiodarone alone [21]. The CASH study including also a limited group of 288 patients and realized according to the same protocol as the two previous studies concluded to a nonsignificant decrease in the mortality of 23% at 9 years in comparison to the groups treated medically by amiodarone or metoprolol alone [19]. Due to the restrained sample size, these two studies were not significant. A meta-analysis merging these three studies allowed to conclude significantly in a reduction of 27% in the global mortality of the ICD group and more particularly when left ventricular ejection fraction is ≤35%. The recommendations concerning the indications ICD implantation in secondary prevention of sudden death are as follows: [2–5]

- Cardiac arrest because of ventricular tachycardia or fibrillation without any acute or reversible cause such as a drug intoxication or an ischemic heart disorder with the possibility of revascularization
- Symptomatic spontaneous steady ventricular tachycardia, with or without a detectable cardiac anomaly, for which a medical treatment or an ablation cannot be realized or has failed
- Syncope of unknown cause with ventricular tachycardia or triggerable ventricular tachycardia, in the presence of an underlying cardiac anomaly (especially if the left ventricular ejection fraction is ≤35%)

6.4 Perioperative Management of the ICD

The objective of the active management of a patient with an ICD is to promote optimal conditions of safety and security by limiting the complications such as the inappropriate activation of the ICD or its incorrect deactivation in the event of ventricular arrhythmias.

The events specifically related to the ICD intraoperatively are the following: [4, 22]

- Damage to the generator or the leads
- Failure of defibrillation or an inappropriate shock
- Deregulation of the pacemaker associated with the ICD or of the defibrillator itself with electrical reset and default to a particular setting depending on the manufacturer and device with cancelation of the parameters specific to the patient

These events may obviously aggravate the morbidity and the mortality of such patients and furthermore may result in cancelation or delay of the surgery with resulting prolongation of the hospitalization and additional cost [5].

6.4.1 Preoperative Period

During the preoperative consultation, it is fundamental to appreciate any incident which may be connected to the malfunction of the ICD by noting the indication for device implantation, the device type, manufacturer and model, device response to magnet placement (mode of inhibition), and whether the patient is pacemaker dependent.

If no prospective study estimated the impact of an inadequate preoperative evaluation of an ICD, there are nevertheless a number of published case reports in which a deficient evaluation has resulted in intraoperative problems [4, 22]. During the preoperative consultation, it is thus essential to question the patient concerning the information on his ICD information card, device type and manufacturer, the current programming, and whether the patient is pacemaker dependent. If the patient is not capable of supplying the required informations, it is essential to contact the cardiac electrophysiologist in charge for adding this information clearly in the medical record.

Examination of the electrocardiogram may indicate the presence of a pacemaker and whether it is functional. The presence of a pacing spike preceding every complex would suggest that the patient is pacemaker dependent. A Valsalva maneuver can unmask the activity of a silent pacemaker during the bradycardia inferred by this operation. The response to magnet placement will allow distinction between a pacemaker and ICD. After application of a magnet, an asynchronous mode of pacing is manifest with a pacemaker (typically VOO), whereas the magnet will suspend arrhythmia detection in the ICD while leaving the pacemaker function intact. The chest X-ray may also be useful to demonstrate the presence of an ICD which is characterized by a right ventricular lead with thick radiopaque sections representing the high voltage coils. The lead configuration may distinguish between a single-chamber pacemaker and double-chamber pacemaker depending on the presence of leads in the right atrium and ventricle simultaneously, while a lead passing through the coronary sinus toward the left ventricular border will indicate a biventricular device for resynchronization.

6.4.2 Prevention of Electromagnetic Interferences (EMI)

Although much progress has made in terms of isolation, EMI can be interpreted by a pacemaker as intrinsic cardiac activity, especially when monopolar electrocautery is used in close proximity to ICD. To limit the EMI nuisance, it is recommended to use preferentially a bipolar cautery. Nevertheless, when unipolar electrocautery is used, it is recommended to place the dispersal patch so as to direct the current away from the pulse generator without passing through it. It is also recommended to use the electrocautery in a sequenced, irregular way and with the lowest possible intensity to limit the EMI. Whatever, the ICD anti-tachyarrhythmia or defibrillation functions should be turned off for the intraoperative period. There are two possibilities for this: first, preoperative ICD reprogramming by the electrophysiologist and, second, inhibition by a magnet applied to the ICD during

intraoperative period. In the case of reprogramming by the cardiac electrophysiologist, the patient must be equipped with an external defibrillator positioned in anterior-posterior configuration on the chest, as far as possible from the ICD generator. External defibrillator patches have to be positioned perpendicular to the ICD leads, for decreasing the risk of high voltage current in ICD leads, what would have the consequence of burning the myocardium due to the intensity of the shock—300 J as opposed to the usual 36 J delivered by ICD. The external defibrillator must be positioned before the reprogramming takes place and maintained until reactivation.

In the case of inhibition by application of a magnet, a safe and recognized method [5], the anti-tachyarrhythmia and cardioversion functions are suspended. When the magnet is applied in a continuous way, a tone coupled with the wave R testifies the inactivation of the device. On withdrawal of the magnet, these activities are restored. In case of intraoperative ventricular tachycardia or fibrillation episodes, the magnet can be removed from the case to obtain an internal electric shock. In parallel, as a safety precaution however, external defibrillator must always be set up as described above and prepared for immediate use. In addition, it is important to remember that if the application of the magnet inhibits of the ICD, associated pacemaker is not affected and will not pass to an asynchronous mode (VOO or AOO) as is the case for a patient with an isolated pacemaker. Thus if the patient is pacemaker dependent, this reprogramming must be carried out by an appropriate specialist with a device programmer before the beginning of the procedure [5, 22].

6.4.3 Intraoperative Management

Strict monitoring of the heart rate and rhythm of the patient with an ICD is crucial during the inoperative period. As the ECG may potentially be perturbed by EMI as well, supervision of the heart rhythm may be usefully carried out by the pulse oximeter or the arterial waveform if invasive arterial pressure monitoring is present [4, 5, 22]. The presence of EMI may lead to over sensing by the pacemaker with consequent inhibition of pacing. Limiting the duration of the applications of EMI may be effective; otherwise, magnet placement is imperative. In the case of ventricular fibrillation or tachycardia, the ICD may be reactivated rapidly by removal of the magnet. Otherwise external cardioversion may be used.

For anesthesia protocol by itself, anesthetic agents do not interfere with ICD. Apart from the electrocautery, other potential sources of EMI include fasciculation (suxamethonium), electric shaving in the proximity of the ICD generator, and high tidal volumes [5]. These elements should be avoided if possible.

6.4.4 Postoperative Management

The American recommendations suggest that all ICD should be verified by a electrophysiologist following a surgical operation [4]. By considering the increasing

number of patient implanted with this device (plan), it seems unreasonable to verify every ICD after the surgery, this especially as 77% of cardiac electrophysiologists consider that it is inequitable [4, 5]. Thus, ESC/ESA recommends to control the device only when there has been a nonadapted anti-tachyarrhythmia or defibrillation episodes or in case of evident dysfunction [5, 22]. In the case of administration of an external electric shock, the device will be systematically interrogated [5, 22].

Moreover certain consider as crucial to check the ICD after cardio-thoracic surgery when there is a risk of mobilisation of the lead tips [2].

6.4.5 Specific Conditions

In the case of radiofrequency, ICD should be inhibited, likewise for lithotripsy. Of course, magnetic resonance imaging is formally contraindicated.

6.5 Key Points in the Perioperative Management of the Patient with a CIED

6.5.1 Preoperative Period

The anesthetic consultation must determine systematically:

- Indication (primary or secondary prevention, associated cardiac insufficiency)
- Device type, manufacturer (Medtronic ®, Biotronik ®, Sorin ®, St Jude ®, Medico ®)
- Presence of a pacemaker with unipolar or bipolar leads
- Current programming mode of ICD and the pacemaker DDD, DDI, VVI, AAI
- Patient pacemaker dependent or not
- Systematic ECG

6.5.2 Intraoperative Period

- Preferably bipolar electrocautery or otherwise, if unipolar electrocautery is used, it is recommended to place the dispersal patch so as to direct the current away from the pulse generator without passing through it.
- Inhibition of the ICD by apposition of a magnet. The anti-tachyarrhythmia and fibrillation detection will be inactivated by magnet whereas the pacemaker function is not affected. Then, the pacemaker will not change to an asynchronous mode, and patient is exposed to low cardiac output in the case of EMI. Therefore, in case of pacemaker dependent, reprogramming must be performed by a cardiologist with a specific device programmer before performing the surgery.
- External defibrillator in position and functional
- Continuous monitoring of the pulse oximetry or blood pressure curve throughout the period of inhibition of the ICD, in the operating theater and ICU

- Prompt removal of the magnet or an external shock in the case of ventricular arrhythmias or fibrillation with cessation EMI
- Postoperative interrogation by the cardiologist in case nonadapted ICD activity, external defibrillation, or device dysfunction has occurred during intraoperative period.

Conclusion

Because of the exponential increase of the number of patients with ICD, the anesthesiologist is required to undertake the perioperative management of this population more and more frequently. Then, it is imperative for the physician to know the indications, the functioning, and, in addition, the means of preventing and treating the problems usually related to the presence of perioperative EMI. It must be understood that the management of the underlying cardiac pathology remains the main concern, with most of patients having left ventricular function less than 35%. A preoperative evaluation of the patient is crucial, the physician making the decision of reprogramming the device or to use a magnet application to inhibit it as appropriate. Then, the dependence or not to pacemaker function is crucial point to make the decision. Thus the patient can be managed in the conditions of security required.

Key Points

- With the exponential increase in the number of cardiac defibrillators implanted (ICD) in the last decade, the anesthesiologist is confronted more and more frequently with the management of these patients in the perioperative period.
- It is therefore imperative to understand the indications and the functioning of these devices in addition to predicting potential problems which may occur and their treatment and implications.
- In addition to the problems related to the defibrillator, it must be remembered that these patients require a thorough cardiac evaluation due to their underlying pathology.
- The defibrillator, like the pacemaker with which it is associated, is sensible to electromagnetic interferences (EMI) which should be limited as far as possible by the use of bipolar electrocautery.
- If unipolar electrocautery is used, it is recommended to place the dispersal patch at a distance from the ICD and in such a way as to prevent the electric arc passing through the generator.
- The anti-tachyarrhythmia and defibrillation functions of the ICD can be inactivated by application of a magnet on the device. Nevertheless, in the case of an associated pacemaker, the ICD will be inhibited by the magnet whereas the pacemaker function remains unchanged. It means the pacemaker will not change to an asynchronous mode. If the patient is pacemaker dependent, reprogramming must be carried out by a cardiac electrophysiologist with a device programmer.
- The defibrillator should be interrogated in the case of a nonadapted anti-tachyarrhythmia or defibrillation episode during intraoperative period or following an external choc or in case of any evident dysfunction.

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