The implantable cardioverter defibrillator

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The implantable cardioverter defibrillator is the optimal treatment for both primary and secondary prevention in patients with previous aborted sudden death and with life-threatening cardiac arrhythmias. This article will review the indications and the evidence supporting implantable cardioverter defibrillator use.

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Cardiovascular disease is responsible for over 300 000 deaths each year in the UK with over 70 000 of those from sudden cardiac death caused by ventricular tachycardia (VT) or ventricular fibrillation (VF). Only 2–30% of patients with cardiac arrest survive (de Vreede-Swageemakers et al, 1997) and a number of these will have further events which if untreated are usually fatal. Antiarrhythmic therapy is ineffective in improving mortality in high-risk patients. The implantable cardioverter defibrillator (ICD) was introduced into clinical medicine in 1980 (Mirowski et al, 1980) and can actively sense and terminate life-threatening ventricular tachyarrhythmias.

This article will review the evidence supporting the use of ICDs and which patients should be considered for implantation. It will also cover practical aspects of ICD implantation and discuss current and future advances in ICD technology.

EVIDENCE BASE FOR THE ICD

A large body of evidence now exists to support the use of ICDs as first-line treatment for both primary and secondary prevention of life-threatening arrhythmias (Mirowski et al, 1980; Moss et al, 1996; Antiarrhythmics *vs* Implantable Defibrillators (AVID) Investigators, 1997; Buxton et al, 2000; Connolly et al, 2000a) (*Table 1*).

TABLE 1.
Major trials demonstrating superiority of the implantable cardioverter defibrillator over conventional medical therapy

Secondary prevention	Antiarrhythmics *vs* Implantable Defibrillators (AVID) (1997)
	Canadian Implantable Defibrillator Study (CIDS) (Connolly et al, 2000a)
	Cardiac Arrest Study Hamburg (CASH) (Kuck et al, 2000)
Primary prevention	The Multicenter Automatic Defibrillator Implantation Trial (MADIT) (Moss et al, 1996)
	Multicenter Unsustained Tachycardia Trial (MUSST) (Buxton et al, 2000)
	MADIT 2 (Moss et al, 2002)

Secondary prevention

The AVID study (1997) included 1016 patients who were either resuscitated from an episode of near fatal VF, or had sustained VT requiring cardioversion or patients with VT with syncope and an ejection fraction (EF) <40%. Patients were randomized to receive an ICD or class III antiarrhythmic therapy (primarily amiodarone). Overall survival was improved in the ICD group with reductions in mortality of 39%, 27% and 31% at 1, 2 and 3 years respectively.

The superiority of the ICD over amiodarone has been confirmed in two other secondary prevention trials: the Canadian Implantable Defibrillator Study (Connolly et al, 2000a) and the Cardiac Arrest Study Hamburg (Kuck et al, 2000). A meta-analysis of these three trials (Connolly et al, 2000b) shows a 28% reduction in the relative risk of death that is almost entirely the result of a 50% reduction of arrhythmic death. The greatest mortality benefit was seen in those with worse left ventricular (LV) function (EF <35%). ICDs significantly reduced deaths in such patients; patients live 0.36 years longer on average. For every 10 patients treated with an ICD one death was averted in the first 3 years. ICD implantation is now considered first-line therapy in such patients.

Primary prevention

The fact that only a minority of patients survive a cardiac arrest mandates that treatments should be offered to high-risk patients before they have

suffered an event. Unsustained VT in patients with previous myocardial infarction (MI) and LV dysfunction is associated with a 2-year mortality rate of about 30% (Buxton et al, 2000). Several studies have examined the benefit of the ICD in this high-risk group and have shown the superiority of the ICD over medical treatment (Moss et al, 1996; Buxton et al, 2000). The Multicenter Automatic Defibrillator Implantation Trial (MADIT) (Moss et al, 1996) studied 196 patients with prior MI and a LV EF <35% who had a documented episode of asymptomatic non-sustained VT that was inducible at electrophysiological study (EPS). Patients were randomly assigned to receive an ICD or conventional medical therapy (only 10% of patients were taking amiodarone). During an average follow-up of 27 months, there was a significant mortality reduction in the ICD group from over 32% to approximately 10%. Subsequently the Multicenter Unsustained Tachycardia Trial (MUSST) studied 704 patients with coronary artery disease, an EF <40% and inducible VT. There was a significant reduction in mortality at 2 years follow up from 33% in the group not receiving an ICD to 10% in the ICD-treated group.

Another primary prevention trial CABG Patch studied 900 patients undergoing coronary artery bypass grafting (CABG) with impaired LV function (EF<36%) and an abnormal signal averaged electrocardiogram and showed no benefit of the ICD. Thus not all groups appear to benefit from ICD use (Bigger, 1997).

The recently published MADIT 2 study (Moss et al, 2002) examined 1232 patients with previous MI and an EF <30%. Unlike MUSST and MADIT patients had no history of ventricular arrhythmias. Patients were randomized to receive either an ICD or conventional medical therapy. After 20 months of follow up there was a significant mortality benefit with the ICD with a 31% reduction in the relative risk of death (absolute reduction of 6%). The benefit was not as great as in ICD studies that used EPS to risk stratify patients (Moss et al, 1996; Buxton et al, 2000) but was nevertheless substantial. An interesting finding of MADIT 2 was a higher incidence of new or worsening heart failure (also shown in the CABG Patch study). It was suggested that this is because patients with ICDs live longer thus allowing time for heart failure to develop.

The question of whether all ischaemic patients with significantly impaired LV function receive an ICD has been addressed in a recent editorial (Bigger, 2002). The MADIT 2 data suggest that the greatest mortality benefit was in certain subgroups (e.g. severely impaired LV function, wide QRS morphology). The ICD-treated group had an EPS at implantation and it will be important to see whether the most substantial benefit was in those patients with inducible VT. If this were the case then EPS would remain an essential part of the ICD work up. There are other ongoing ICD studies including the Sudden Cardiac Death in Heart Failure Trial (Zivin and Bardy, 1999), which includes patients with heart failure (EF <36% with both ischaemic and non-ischaemic causes) and randomizes them to receive placebo, amiodarone or an ICD. This study should demonstrate whether the ICD is superior to amiodarone for primary prevention in patients with heart failure.

CURRENT INDICATIONS FOR ICD IMPLANTATION

The National Institute of Clinical Evidence (NICE) (2000) has published guidelines for ICD implantation (*Table 2*). They recommend that ICDs should be considered routinely for secondary prevention in cardiac arrest survivors as well as patients with VT and syncope, patients with haemodynamic compromise and those with VT and an EF <35%. For primary

TABLE 2.
Current indications for implantable cardioverter defibrillator implant

Secondary prevention*	Cardiac arrest as a result of VT/VF	
	Spontaneous sustained VT with syncope/significant	
	Haemodynamic compromise	
	Sustained VT (without syncope/cardiac arrest), with an EF <35%†	
Primary prevention	Patients with previous myocardial infarction and all of the following:	Non-sustained ventricular tachycardia on Holter monitoring
		Inducible VT at EPS
		LV EF <35%†
	For patients with familial conditions with a high risk of sudden death including	Long QT syndrome
		Hypertrophic cardiomyopathy
		Brugada syndrome
		Antirhythmogenis right ventricular dysplasia
		Following repair of tetralogy of Fallot
Implantable cardioverter defibrillators not routinely recommended for the following	Sustained VT with minimal symptoms and good LV function (EF >35%)	
	Syncope of unknown cause (no previous myocardial infarction) and inducible VT at EPS with normal LV function (EF >35%)	
	Syncope of unknown origin, haemodynamically significant sustained VT/VF at EPS with impaired LV function (EF <35%)	

From National Institute of Clinical Excellence (2000). *in the absence of a treatable cause (e.g. acute myocardial infarction, temporary electrolyte disturbance); † no worse than New York Heart Association class III heart failure. EF = ejection fraction; EPS=electrophysiological study, LV = left ventricular; VF = ventricular fibrillation; VT = ventricular tachycardia

prevention in line with MADIT and MUSST those patients with ischaemic heart disease an EF<35% and non-sustained VT on Holter monitoring which is inducible at EPS are also considered candidates for ICD implant. ICDs are also indicated for certain (but not all) patients with high-risk familial conditions (*Table 2*). NICE recommends that ICDs should not be routinely considered for:

1. Patients with VT with minimal symptoms and good cardiac function
2. Patients with syncope of unknown cause (without previous MI) with inducible VT at EPS and normal cardiac function (EF >35%)
3. Patients with syncope of unknown origin, with haemodynamically significant sustained VT or VF induced at EPS and in the presence of impaired cardiac function (EF <35%).

ICD IMPLANTATION AND FOLLOW UP

Initially ICD leads were epicardial, requiring a thoracotomy, but now leads are implanted transvenously in the same manner as a pacemaker. The 'shock' lead which delivers the energy required for defibrillation and also paces and senses within the heart is placed via the subclavian or cephalic vein to the right ventricular apex. The generator or 'box', which is approximately 40 cc in volume, is implanted subcutaneously or submuscularly in the left pectoral area. Tests are carried out to ensure adequate pacing and sensing and then VT or VF is induced to ensure that the device can successfully detect and treat the arrhythmia. In Guy's and St Thomas's NHS Trust the majority of devices are implanted using local anaesthesia and patients stay in hospital for 2–4 days.

Current ICDs have a battery life of up to 9 years, but longevity is dependent on the number of shocks delivered and the amount of pacing. Patients are followed up regularly in a dedicated ICD clinic where the device can be interrogated and reprogrammed as required (routinely every 6 months). ICD patients are unable to drive for 6 months after implantation or after a shock is delivered (Jung et al, 2002). Early complications of ICDs can be associated with implantation, with risks similar to those of pacemaker implantation including pneumothorax, pericardial effusion, tamponade and infection. Patients are at risk of receiving inappropriate therapy during follow up with up to 20% of patients receiving inappropriate shocks for rhythms that are not VT or VF, usually as a result of atrial fibrillation (Grimm et al, 1992).

ICD TECHNOLOGY: CURRENT AND FUTURE ADVANCES

There have been significant technological advances since the introduction of the ICD. Initial devices were capable of delivering shock therapy but the current generation of devices incorporate dual chamber pacing, enhanced arrhythmia detection algorithms and tiered therapy. Current ICDs are able to discriminate between a number of arrhythmias and may reduce the incidence of inappropriate shocks. A large proportion of ventricular arrhythmias can now be terminated by using antitachycardia pacing which can prevent the need for shock delivery. During their lifetime more than 50% of ICD patients may develop atrial fibrillation (Schmitt et al, 1998). There are implantable atrial defibrillators which will deliver shock therapy to cardiovert atrial fibrillation. Similarly dual chamber defibrillators with the ability to specifically cardiovert atrial arrhythmias as well as ventricular arrhythmias are in use (Santini and Ricci, 2001).

Cardiac resynchronization therapy achieved with biventricular pacing (Cazeau et al, 2001) can now be incorporated with biventricular ICDs and may offer symptomatic relief for heart failure patients with discoordinate ventricular function. The incidence of biventricular ICD use may well increase significantly as a large proportion of ICD patients have heart failure and broad QRS morphology. In the MADIT 2 study (Moss et al, 2002) the average EF was 23% and 50% of patients had a QRS duration >0.12 msec. As mentioned earlier the observed increase in heart failure in ICD-treated patients (Bigger, 1997; Moss et al, 2002) may lead to an increased need for biventricular pacing.

COST EFFECTIVENESS OF ICDS

Cost effectiveness remains a critical issue regarding defibrillator therapy (Hlatsky and Bigger, 1997). Current ICD systems cost around £20 000, but this is subject to contractual agreements and company discounts. The incremental costs of the treatment are dependent on the number and length of hospital admissions. ICDs tend to reduce hospitalization for arrhythmic episodes but this could be offset by an increased incidence of admissions from heart failure (Moss et al, 2002).

For secondary prevention data from the AVID trial suggests a cost per life year gained of £26 000–31 000, using a 5-year model with ICD replacement where necessary. As the longevity of devices increases cost effectiveness would expected to be more favourable. Increased sales volumes of ICDs are likely to lead to lower cost

ICDs. The cost-effectiveness of ICD therapy varies by patient risk factor status with more favourable cost effectiveness in high-risk groups (Sheldon et al, 1997). Thus risk stratification will remain an important tool; the ideal ICD patient would be someone at high risk of death from cardiac arrhythmia but not from other causes. The impact of ICDs on the quality of life of patients is important. Data from the AVID trial suggest improved mental wellbeing in patients whose devices are rarely or never activated compared with patients whose devices are often activated.

CONCLUSIONS

The annual implant rate for ICDs in the UK in 1999 was 17 per million compared to an implant rate of 185 per million in the USA and an average for Western Europe of 30 per million (National Institute of Clinical Excellence, 2000). The number of implants in the UK is estimated to rise from 17 per million population to the order of 50 per million, which would translate to 1800 implants and a budget impact for the NHS of £45 million per year (National Institute of Clinical Excellence, 2000). There is now a firm evidence base as to which patients should receive ICD implantation. There is a need, however, to develop protocols for screening high-risk subjects to ensure early referral of appropriate patients. There is a need to develop a rehabilitative approach to after-care, including psychological preparation for living with an ICD, early discharge, and efficient and comprehensive follow-up, which will have important training and funding implications for the NHS. **HM**

Conflict of interest: none.

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KEY POINTS

- Implantable cardioverter defibrillator therapy is effective in treating malignant ventricular arrhythmias.
- Implantable cardioverter defibrillators are considered first-line therapy for secondary prevention (cardiac arrest survivors and those with ventricular tachycardia and syncope or with ventricular tachycardia and significant left ventricular dysfunction) and primary prevention (ischaemic heart disease and significant left ventricular dysfunction with non-sustained ventricular tachycardia inducible at electrophysiological study.
- Current devices are implanted transvenously without the need for general anaesthesia, requiring a short hospital stay.
- Current devices are able to perform multiple functions and can pace and terminate arrhythmias, negating the need for shock therapy.
- New developments include ability to terminate atrial arrhythmias and biventricular pacing to achieve cardiac resynchronization.
- Cost effectiveness remains an important issue.
- Implant rate in UK is rising dramatically with important issues of funding and training for the NHS.