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PICTORIAL REVIEW

Keeping up appearances: the radiographic evolution of cardiovascular implantable electronic devices

¹BENEDICT M WILES, MA, MRCP, ²CAROLINE A ILLINGWORTH, BSc, MRCP, ¹JOHN R PAISEY, DM, FRCP,
¹PAUL R ROBERTS, MD, FRCP and ²STEPHEN P HARDEN, MA, FRCR

¹Cardiac Rhythm Management Research Department, University Hospital Southampton NHS Foundation Trust, Southampton, United Kingdom

²Cardiothoracic Radiology Department, University Hospital Southampton NHS Foundation Trust, Southampton, United Kingdom

Address correspondence to: Dr Benedict M Wiles

E-mail: benedict.wiles@uhs.nhs.uk

ABSTRACT

In recent years, there has been a significant evolution in the field of cardiovascular implantable electronic devices (CIEDs). Pacemakers can now be leadless, implantable cardioverter defibrillators can be entirely subcutaneous and implantable loop recorders have become miniaturized. Driven by technological advances and an ageing population implant numbers have also steadily increased. These highly prevalent systems are all radio-opaque and are frequently observed on chest radiographs, yet the devices are neither well recognized nor understood. We present a pictorial review of CIEDs; describing the chest radiograph appearances of both newer generation systems and their traditional predecessors. Furthermore, we discuss the clinical role of chest radiography in both CIED implantation and follow up, with the aim of improving understanding in this important and expanding field. Finally, we present a collection of interesting and challenging radiographs, where multiple CIED systems have been implanted.

INTRODUCTION

The first implantation of a permanent pacemaker was performed in Sweden in 1958. Inserted via a surgical thorotomy and comprising a large abdominal wall generator, the system functioned for just 3 h.¹ Yet, by the start of the 21st century cardiovascular implantable electronic device (CIED) implantation had become a rapidly developing field of medicine; incorporating permanent pacemakers, internal defibrillators and long-term cardiovascular monitoring devices.

CIED implantation rates have steadily increased across Europe. In developed economies, device prevalence has doubled over the last 15 years, a trend which is set to continue as implant incidence is strongly correlated with advancing age.² Increasing prevalence has been matched by a parallel expansion in device technology, allowing smaller more sophisticated devices to come to market. The cardiac device landscape develops quickly; pacemakers can now be leadless, implantable cardioverter defibrillators (ICD) can be entirely subcutaneous and implantable loop recorders (ILR) have become miniaturized.

CIEDs are radio-opaque and have been frequently observed on radiological studies for a number of decades. However, the appearance of newer generation CIEDs is significantly different from those of their predecessors and consequently, these newer devices are neither well recognized nor understood. We present a pictorial guide to aid correct identification of all CIEDs on a chest radiograph and to highlight the clinical role of chest radiography in their implantation and follow up.

PERMANENT PACEMAKERS

The permanent pacemaker remains the only effective treatment for symptomatic bradycardia and the most prevalent CIED. Implantation is low risk and can be performed under local anaesthesia, increasingly as a day case procedure, even in elderly patients.

Traditional pacemaker systems are comprised of a pulse generator, implanted in a prepectoral subcutaneous position and a number of transvenous leads. The leads are connected proximally to the pulse generator and fixated distally to the myocardium. Lead number and configuration vary according to pacing need. A dual chamber

Figure 1. PA and lateral chest radiographs showing an implanted dual chamber pacemaker. The pulse generator is in a left-sided prepectoral position. The RA lead is positioned in the appendage, while the RV lead is at the apex of the ventricle. RA, right atrial; RV, right ventricular.

pacemaker comprises an atrial lead implanted in the right atrial appendage, and a ventricular lead implanted at the right ventricular (RV) apex or septum (Figures 1 and 2).

The majority of pulse generators are left sided as this makes surgical aspects of the procedure and lead manipulation more ergonomic for right-handed operators. Right-sided implants are often reserved for patients with a previously explanted left-sided system, although, may be performed for patient preference. Pacemaker lead extraction is challenging and associated with both morbidity and mortality. Damaged or malfunctioning leads may, therefore, be abandoned rather than removed.³ Interpretation of the chest radiograph can become challenging as both current and abandoned leads are visualized.

Figure 2. PA chest radiograph showing a right-sided dual chamber pacemaker. Unlike Figure 1, the RV lead is placed in the interventricular septum rather than at the ventricular apex. RA, right atrial; RV, right ventricular.

Figure 3. PA and lateral chest radiographs showing an implanted CRT device. The hallmark of CRT is the presence of an LV lead; which can be seen to pass from the right side of the heart to the left lateral border of the cardiac silhouette. The LV lead runs through the coronary sinus and rests in an epicardial venous tributary. The absence of a defibrillator coil on the RV lead means this is a CRT-P (pacemaker) and not a CRT-D (defibrillator). CRT, cardiac resynchronization therapy; LV, left ventricular; RA, right atrial; RV, right ventricular.

Cardiac resynchronization therapy (CRT) is a well-established treatment for patients with left ventricular (LV) systolic dysfunction and asynchronous LV contraction, improving quality of life and reducing heart failure-related hospitalizations and mortality.⁴ The hallmark of a CRT device is the presence of an LV lead. These are placed into a vein on the surface of the left ventricle via the coronary sinus which drains into the right atrium. On the chest radiograph, they are seen to pass posteriorly on the lateral projection (Figure 3).

Fluoroscopy is utilized during both pacemaker and CRT implantation to facilitate lead placement, with PA and lateral chest radiographs used to document final lead position. Where subclavian or axillary venous access is used, the radiograph can also exclude an asymptomatic ipsilateral pneumothorax, with imaging delayed 4–6 h to allow accumulation of air in the pleural space. During device follow up, chest radiographs are indicated

Figure 4. (Left) Diagram showing the MICRA leadless pacemaker (Medtronic Inc., MN, USA) *in situ* in the right ventricle. (Right) Diagram showing the size of a MICRA leadless pacemaker compared with a traditional transvenous single chamber pacemaker with right ventricular lead (Medtronic Inc., MN, USA).

Figure 5. LAO and RAO chest radiograph projections which accurately show the position of the leadless pacemaker within the heart. The LAO projection confirms that the device is directed towards the interventricular septum and not towards the apex, as this reduces the risk of perforation. LAO, left anterior oblique; RAO, right anterior oblique.

Figure 6. PA and lateral chest radiographs demonstrating an implanted leadless pacemaker. On the PA projection, one might confuse this leadless pacemaker with an implantable loop recorder, although the lateral projection confirms that the device is located within the heart and not subcutaneously.

Figure 7. PA and lateral chest radiographs showing an implanted dual chamber ICD. The presence of a shocking coil at the distal end of the RV lead confirms that this is a defibrillator and not a pacemaker. The shocking coil, annotated by a black rectangle, is thicker in diameter and more radiodense than the remainder of the lead and can be easily identified in both projections. ICD, implantable cardioverter defibrillators; RV, right ventricular.

Figure 8. A comparison schematic diagram of an implanted transvenous ICD and an implanted S-ICD. Copyright Boston Scientific, MA, USA, or its affiliates. Reproduced with permission. S-ICD, subcutaneous implantable cardioverter defibrillators.

where an alteration in pacemaker lead parameters suggests lead displacement or fracture.

LEADLESS PACEMAKERS

The leadless pacemaker is an encapsulated device consisting of a small battery and electrodes capable of sensing and pacing

Figure 9. PA and lateral chest radiographs showing an implanted S-ICD. The shocking coil (annotated by a rectangle) can be clearly identified at the distal end of the lead. The lateral projection shows that the shocking coil is implanted subcutaneously and that the device sits in the axilla. S-ICD, subcutaneous implantable cardioverter defibrillators.

Figure 10. PA and lateral chest radiographs demonstrating an implanted S-ICD in combination with an implanted atrial pacemaker. S-ICD, subcutaneous implantable cardioverter defibrillators.

Figure 11. Size comparison of the Reveal XT (traditional ILR) and the Reveal LINQ (miniaturized ILR). Image courtesy of Medtronic Inc., MN, USA, and reproduced with permission. ILR, implantable loop recorders.

the endocardium. The device is small enough to be percutaneously implanted in the RV via a large bore femoral venous sheath (Figure 4). The absence of transvenous leads offers a significant clinical advantage owing to the many well established issues related to lead complications. Single chamber rate responsive RV pacing can be achieved and the devices are expected to have greater battery longevity than traditional devices. AV synchrony will soon be achieved but CRT cannot be achieved without additional, thus far experimental, adjuncts.

Device implantation is undertaken using fluoroscopy, with imaging in different planes required to confirm optimal device location at the apical septum (Figure 5). There is no risk of pneumothorax during implantation, although chest radiography is frequently employed post procedure to accurately document device location. Dislodgement during follow up is an extremely rare complication which would be easily diagnosed using a chest radiograph.⁵ Owing to their small size, leadless pacemakers can be mistaken for an ILR on a PA radiograph, especially as the latter can lie entirely within the cardiac silhouette. The addition of a lateral radiograph makes the devices easily distinguishable given that the leadless pacemaker lies within the heart chambers and not in the subcutaneous tissue (Figure 6).

Figure 12. PA and lateral chest radiographs showing an implanted Reveal LINQ device.

Figure 13. PA radiograph showing a traditional sized loop recorder device *in situ*.

IMPLANTABLE CARIOVERTER DEFIBRILLATORS

ICDs are an important treatment for ventricular arrhythmias, consistently demonstrating superiority to medical therapy in trials of both primary and secondary prevention of sudden cardiac death (SCD).^{6,7} Technological advances and improved recognition of patients at risk of sudden cardiac death have broadened the clinical indications for device therapy with ICD implantation rates continuing to rise.⁸

Figure 14. PA chest radiograph showing an implanted S-ICD (+) in combination with a deactivated transvenous ICD (RV) and a subcutaneous array (*). The array is an additional shocking coil which is implanted subcutaneously and connected to the transvenous ICD, it offers alternative shocking vectors and is implanted after failure of defibrillation to improve shock efficacy. RV, right ventricular; S-ICD, subcutaneous implantable cardioverter defibrillators.

Figure 15. PA chest radiograph showing an implanted S-ICD (+) in combination with several abandoned leads: namely those of a single chamber dual coil transvenous ICD (RV), a subcutaneous array (*) and surgically placed epicardial pacing leads, atrial (A) and ventricular (V). Sternal wires (^) from a midline sternotomy can also be seen. RV, right ventricular; S-ICD, subcutaneous implantable cardioverter defibrillators.

The conventional ICD has an extremely similar radiographic appearance to that of a permanent pacemaker. The pulse generator is located in the same prepectoral position as for a pacemaker and while the ICD pulse generator is larger than that of an equivalent pacemaker, significant variations in size exist between different ICD manufacturers and systems. ICDs are more likely

Figure 16. PA chest radiograph showing an implanted CRT-D (defibrillator). This is an unusual image as the patient has a persistent left-sided SVC, which was discovered at the time of implant. The SVC drains directly into the coronary sinus allowing easy placement of the LV lead, while the RV lead is looped around the right atrium and across the tricuspid valve to its usual location at the RV apex. CRT, cardiac resynchronization therapy; LV, left ventricular; RV, right ventricular; SVC, superior vena cava.

Figure 17. PA and lateral chest radiographs showing an implanted S-ICD (+), an epicardial CRT-P (pacemaker) device located in the abdomen (^) and an abandoned section of transvenous RV lead (RV). CRT, cardiac resynchronization therapy; RV, right ventricular; S-ICD, subcutaneous implantable cardioverter defibrillators.

to be implanted on the left side as the casing of the device is usually active, acting as one of the defibrillation electrodes.

The hallmark of an ICD system, distinguishing it from a pacemaker radiographically, is the presence of a shocking coil (Figure 7). At least one shocking coil is required to facilitate the passage of high energy through the heart to achieve defibrillation. Multiple coils increase the available shocking vectors but increase the risk of future lead extraction.

ICD systems can be single chamber (RV), dual chamber (right atrial and RV) or provide CRT (additional LV lead). The requirement for fluoroscopy during implant and the indications for chest radiographs are identical to those described for permanent pacemakers.

SUBCUTANEOUS ICD

In recent years, the subcutaneous ICD (S-ICD) has emerged as an alternative to traditional transvenous ICD systems. The S-ICD consists of a large pulse generator implanted in a posterior left axillary position with a single lead. The lead is tunnelled subcutaneously across the anterior thorax and parallel to the sternum. The heart lies between the shocking coil at the distal aspect of the

Figure 18. PA and lateral chest radiographs depicting a right-sided S-ICD (+), a dual chamber pacemaker and an abandoned atrial lead (^) in a patient with dextracardia. S-ICD, subcutaneous implantable cardioverter defibrillators.

lead and the pulse generator allowing high energy defibrillation (Figure 8).

The S-ICD does not enter the heart or vascular system and is not exposed to the repetitive contractions of the cardiac cycle or the hostile environment of the vasculature.⁹ S-ICD lead longevity is, therefore, expected to be greater than that of transvenous systems, while registry data shows comparatively lower major complication rates for S-ICD implantation.¹⁰ The S-ICD cannot currently be used in patients who require permanent pacing. A strategy for pairing the S-ICD with a leadless pacemaker is under evaluation.

The S-ICD is easily identifiable on a chest radiograph as the lead can be seen to travel outside of the cardiac silhouette (Figure 9). Patients will occasionally have both a permanent pacemaker and an S-ICD *in situ* (Figure 10). Device implantation is guided by anatomical landmark techniques with fluoroscopy used at the discretion of the operator. Routine chest radiographs are not required during implantation and are rarely indicated during follow up.

IMPLANTABLE LOOP RECORDERS

The ILR is a small implantable device that provides a temporal correlation between cardiac rhythm and intermittent symptoms such as syncope or palpitation. Implanted subcutaneously under

local anaesthetic ILRs have a battery life of up to 3 years and combine patient activated and automated rhythm recordings. Implantation does not require X-ray imaging.

Newer generation ILRs; LINQ™ (Medtronic Inc., MN, USA) and Confirm RX™ (St Jude Medical, MN, USA) are considerably smaller than traditional devices (Figure 11). They are injected subcutaneously on the anterior chest wall and can be easily identified on a chest radiograph (Figures 12 and 13).

CONCLUSIONS

This pictorial review of chest radiographs shows the evolving appearance of CIEDs and provides information that allows accurate device recognition and improved understanding in this emerging and rapidly developing field. Understanding the basic principles of CIED recognition allows accurate reporting even where CIEDs are used in unusual and challenging combinations (Figures 14–18).

CONFLICTS OF INTEREST

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