There has been an exponential increase in catheter ablation procedures performed in the UK, for the treatment of cardiac arrhythmias, over the last decade. This has been particularly notable for the treatment of atrial arrhythmias such as atrial flutter, atrial fibrillation, and atrio-ventricular nodal re-entry tachycardias (AVNRTs). Atrial fibrillation (AF) ablation procedures have increased from <100 per yr in 2000 to over 3500 procedures in 2009. Anaesthetists are increasingly becoming involved in the provision of sedation or general anaesthesia for these procedures. There is a marked (10-fold) regional variation in cardiac electrophysiology services, with the majority of electrophysiology units concentrated in London and the South East. [178 procedures per million population take place in London compared with 18 procedures per million population in the North East (CCAD).] Technologies for the treatment of arrhythmias are rapidly evolving and these techniques are associated with unique complications.

This article will describe the techniques used by the cardiologists to map the arrhythmias and discuss the different techniques involved in ablation. It will consider the anaesthetic implications of these procedures and discuss the challenges of delivering safe anaesthesia in the cardiac catheter laboratory. Finally, the complications of these procedures will be emphasized to enable prevention, or rapid diagnosis and treatment.

Intracardiac electrograms (e-grams) are recorded from the high right atrium (HRA), coronary sinus (CS), His bundle, and right ventricular apex (RVA). They are supplemented by external ECG leads I, II, III, aVL, V1, and V6. Intracardiac e-grams are recorded to understand the arrhythmia. They guide the ablation catheter to the correct position for ablation and are then used to check the success or failure of the treatment, that is, termination of the arrhythmia at the end of the procedure (Fig. 1).

The origin of arrhythmias

Most arrhythmias are re-entrant passing through a critical isthmus that is amenable to ablation. Energy is delivered at this site to cauterize the endocardium and render it electrically inert.

Right-sided atrial ablation

Atrial flutter ablation

Atrial flutter arises from the right atrium. In 90% of the cases, it is an anti-clockwise circuit, and in 10% of the cases, a clockwise circuit in the right atrium.

A single ablation line is created between the inferior vena cava and the tricuspid valve (cavo-tricuspid isthmus ablation) to interrupt the flutter circuit.

AVNRT ablation

AVNRT is due to a slow pathway of the AV node, lying between the CS and the His bundle.

The slow pathway is amenable to ablation by a single burn. It is usually carried out under local anaesthesia and sedation, to prevent the suppression of the arrhythmia.

Ventricular tachycardia ablation

Ventricular tachycardia is a focal tachycardia, often arising from the right ventricular outflow.

Key points

There has been an exponential increase in catheter ablation procedures for the treatment of cardiac arrhythmias over the last decade. Complex technologies are involved in electrophysiology studies and mapping of arrhythmias. Different ablation techniques and energies are used with unique complications and requirements for anaesthesia. The cardiac catheter laboratory is an isolated environment with specific challenges for the anaesthetist. There are major complications of ablation procedures including cardiac tamponade and oesophageal damage.
tract (RVOT). It is also amenable to a short ablation procedure of the ventricular tachycardia (VT) focus.

**AV re-entry tachycardia**
AV re-entry tachycardia is due to an accessory pathway on the AV ring, on the tricuspid or mitral valve annulus. The pathway is identified by targeted pacing. Tricuspid accessory pathways are ablated with right-sided catheters, whereas mitral pathways require a trans-septal or retrograde trans-aortic approach.

**Left atrial ablation**
AF arises in the left atrium from the four pulmonary vein ostia. Paroxysmal and persistent AF are amenable to ablation. Permanent AF is not usually treated with ablation. Before left atrial ablation, a transoesophageal echo (TOE) is performed to exclude the thrombus in the left atrial appendage. Ablation catheters are passed into the right heart via the femoral vein and inferior vena cava, or subclavian vein. The catheters are passed across the foramen ovale in the intra-atrial septum into the left atrium. Fluoroscopy, TOE, or...
both are used to guide the transseptal puncture. Complications include atrial perforation, aortic perforation, and cardiac tamponade (Fig. 2).

**Catheter navigation systems**

There are various catheter navigation systems for mapping arrhythmias, which are briefly summarized.

**CARTO**

CARTO involves an electromagnetic field created by magnets beneath the catheter table, which resolve the position of a specific CARTO catheter.

**NAVx**

Three pairs of patches on the patient’s back and chest create a transthoracic electric field which resolves the position of the mapping catheter. To create geometry, the catheter is moved along outer boundaries of cardiac chambers and the system records electrode location as points on a map. It displays the connection of these points as a geometric field. Unlike CARTO, the NAVx system resolves the position of any manufacturer’s catheter. These systems create ‘geometry’ which defines the three-dimensional anatomy of the left atrium, or other cardiac chamber. The pulmonary veins are reconstructed and colour-coded, by the CARTO or NAVx software.

**CARTO Merge**

CARTO Merge involves the integration of a cardiac computed tomographic scan, with the mapping data. Any heart chamber can be subtracted from the scan and used in re-construction of the anatomy of that cardiac chamber.

**Wide atrial circumferential ablation**

Figure 3 shows a reconstruction of the left atrium with ablation lines created around the origins of the pulmonary veins. This is known as a wide atrial circumferential ablation. Additional ablation lines may be created along the roof of the left atrium, between the upper and lower veins, between the mitral annulus and lower veins, and on the floor of the left atrium (Fig. 3).

**Non-contact mapping systems: array**

The array balloon is a non-contact mapping system for right-sided arrhythmias. Sixty-four electrodes on the array balloon surface project 64 e-grams. These detect the position of a roving catheter. Mapping data are acquired in one heartbeat. This system is useful in mapping complex right atrial tachycardias, RVOT VT ablation, and in patients with congenital heart disease.

**Ablation energies**

Different energies can be delivered to the endocardium to isolate the source of the arrhythmia or interrupt the aberrant conduction pathway.

**Radiofrequency**

Radiofrequency produces resistive heating with convective heat loss away from the endocardial ablation site. This reduces the energy delivered to the endocardium.

**Radiofrequency with irrigation (Cool Flow)**

Saline is infused over the tip of the radiofrequency ablation catheter. This allows more energy to be delivered and concentrated over a smaller area of the endocardium, producing a deeper lesion or ‘burn’. The system uses large volumes of saline (500–1000 ml in the average AF ablation), which can lead to fluid overload and the possibility of pulmonary oedema.

**Cryo-ablation**

Freezing is used when there are concerns about heart block, that is, when pathways are adjacent to the AV node and there is a risk of damage to normal conduction tissue, for example, AVNRT. The catheter tip is cooled to between −50 and −75°C. The ice ball formation around the catheter tip produces a good stability for ablation, that is, the catheter sticks to the endocardium, and there is a lower risk of thrombus formation at the ablation site. Cryo is reversible if the catheter is only cooled to −30°C. This is useful to check that the ablation site is correct and new problems are not being created such as AV block requiring a permanent pacemaker. The process is slower than other energy systems.

**Low-energy direct current**

This is useful for very deep (i.e. epicardial) accessory pathways which are resistant to treatment by conventional energies. It is old-fashioned and only used occasionally to ablate resistant arrhythmias. More recently, newer balloon-mediated techniques have been developed for AF ablation including cryo-balloon and laser balloon.

**Cryo-balloon or arctic front for AF**

The cryo-balloon consists of a floppy guide wire and a balloon which is inflated with liquid nitrogen. The guide wire is passed into the pulmonary vein and then a 28 mm balloon is inflated in the pulmonary vein ostia, causing vein occlusion. The liquid nitrogen in the balloon is then cooled to −75°C and the whole of the pulmonary vein is isolated by cryo-ablation in one balloon inflation. This is repeated in each of the pulmonary veins. This technique is rapid and has significantly reduced the procedure time.

**Laser balloon**

The catheter balloon is inflated in the pulmonary vein ostia. Laser energy is delivered to isolate the pulmonary veins. An endoscope
and a light source are attached to the laser balloon, allowing the cardiologist to visualize the laser lines created as they ablate. There is emerging evidence to suggest that laser energy may improve long-term results in AF ablation.

**Anaesthesia for ablation procedures**

**Patients and techniques**

Some ablations such as supraventricular tachycardia (SVT) ablation may be more successfully performed under local anaesthesia and sedation in order to prevent suppression of the arrhythmia. However, some patients are unable to lie still, flat, or tolerate the procedure awake. Children, adolescents, and anxious adults require anaesthetic-administered sedation or a general anaesthetic. Adults with congenital heart disease, complex cardiac anatomy, and anticipated long and protracted procedures require general anaesthesia. Procedures involving left atrial ablation and transseptal puncture may also be better performed under general anaesthesia. Patient or cardiologist preference should also be considered.

**Procedures and requirements**

Cardiac ablation procedures can last from anything between 1 and 6 h. They are non-stimulating with little postoperative pain. Radiofrequency is more painful than cryo-ablation. There may be a degree of pericardial irritation that responds to simple analgesics such as paracetamol or non-steroidal anti-inflammatory drugs. The procedures demand absolute immobility, to maintain the accuracy of the mapping and stability of the ablation catheters. There are systems for respiratory compensation within the mapping software, but shallow respiratory volumes to minimize catheter movement are often used. Left atrial septal puncture can be complicated by atrial or aortic puncture, pericardial effusions, and cardiac tamponade. This should always be considered when there is persistent hypotension after transseptal puncture and ablation. It can be rapidly excluded with TOE.

**The cardiac catheter laboratory environment**

The cardiac catheter laboratory is an isolated and a potentially hazardous environment. There are usually no anaesthetic rooms and anaesthesia has to be induced in the lab. It can be noisy with many distractions and the staff are unfamiliar with general anaesthesia and care of anaesthetized patients. This becomes particularly evident during lifting and transferring of unconscious patients.
Positioning

It is important to emphasize the care required in positioning, protection of pressure areas, supporting arms, ankle supports, etc. The catheter lab tables are narrow and often do not tip head down. If they can tip it is essential to have the radiographer in the room during the induction of anaesthesia to move the table if required, as the controls are at the foot of the bed. The catheter laboratory table should have a comfortable mattress to prevent pressure sores. Arms should be carefully padded and wrapped as the patient may have to be defibrillated during the procedure. Head supports are useful, to prevent the patient rolling off the table. Some cardiologists require arms up above the patient’s head to facilitate lateral imaging. Particular care must be taken to prevent brachial plexus injury and the brachial plexus should not be extended beyond 90°. Extensive application of ECG electrodes and sticky patches for mapping, ablation, and defibrillation occurs before the procedure, and this is best done with the patient awake and able to roll themselves.

Temperature

The procedures are protracted, so the patients require active warming. Temperature should be maintained by the use of heat moisture exchangers, fluid warmers, and forced-air warming blankets.

Monitoring

The standard monitoring as for any general anaesthetic is mandatory. Some cardiologists are reassured by an arterial line.

Specific anaesthetic considerations

The challenges of no anaesthetic rooms, non-tipping tables, and the extensive application of electrodes need to be resolved locally depending on the equipment and ergonomics. Some anaesthetists may prefer to induce anaesthesia on a tipping-trolley and then transferring the patient to the catheter table. Patients undergoing left atrial ablation usually need TOE’s and therefore tracheal intubation. The cardiologists give heparin during the procedure, after a safe transseptal puncture to maintain the activated clotting time (ACT) between 250 and 300 s. Vasoconstrictors such as small metaraminol boluses (e.g. 0.5 mg) are frequently required to maintain arterial pressure. It is important to monitor neuromuscular block, to prevent coughing and movement. Remifentanil infusions can reproduce similar conditions. Reduced tidal volumes, with an increased respiratory rate, decrease chest excursion, while maintaining minute ventilation.

Due to the proximity of the left atrium and the oesophagus, and oesophageal mobility, some cardiologists request placement of a nasogastric tube to indicate the oesophageal position. Rapidly reacting oesophageal temperature probes with three thermistors are available, which indicate if the oesophagus is being heated to over 40°C, warning of the potential for oesophageal injury, such as perforation or atrio-oesophageal fistulae. It is also important to withdraw the TOE probe into the proximal oesophagus during ablation, as this will approximate the oesophagus to the left atrium and increase the risk of oesophageal heating and perforation.

The use of the ‘Cool Flow’ for radiofrequency ablation can lead to fluid overload. It is important to monitor fluid balance and administer furosemide, if pulmonary oedema is diagnosed. A urinary catheter may be passed before extubation to empty the bladder and prevent discomfort, restlessness, and agitation on emergence from anaesthesia. As much as 2 litre of urine may be drained. Smooth reversal and extubation is important to control groin haematoma after removal of catheters.

Inhalation or total i.v. anaesthesia?

Controversy surrounds the use of volatile agents for the maintenance of anaesthesia during ablation of arrhythmias. Various studies have addressed this question and compared propofol and isoflurane anaesthesia in children undergoing radiofrequency ablation. Results have failed to demonstrate significant clinical differences between the two agents. Lavoie and colleagues compared the effects of propofol or isoflurane anaesthesia on cardiac conduction in children undergoing radiofrequency ablation for tachy-dysrhythmias and found no difference between the two agents.

Erb and colleagues carried out a similar study in SVT ablation in children and came to similar conclusions. There was no difference in ability to induce SVT; however, AV nodal conduction slowed with propofol and ventricular repolarization was prolonged with isoflurane. This does not translate into clinical practice.

The exception is the treatment of AVNRTs, which are probably suppressed by general anaesthesia, and volatile agents are best avoided. If total i.v. anaesthesia is used for long procedures, the risks of propofol infusion syndrome and metabolic acidosis should be borne in mind.

Interestingly, there is emerging evidence that general anaesthesia may improve outcome in ablation for AF. Di Biase and colleagues randomized 257 patients to conscious sedation (fentanyl and midazolam) or general anaesthesia (GA). Isolation of the pulmonary veins was confirmed at the end of each procedure with an isoprenaline challenge. Failure to provoke AF confirmed the success of the procedure. At 17 months post-procedure, 88% of the general anaesthesia patients were free of arrhythmias compared with 69% of the sedation group. Indeed, the recovery of pulmonary vein conduction had occurred in 42% of the patients who had undergone ablation under sedation compared with only 19% of the GA patients. The authors suggested that general anaesthesia reduces the prevalence of pulmonary vein reconnection compared with sedation.

It is hypothesized that this finding may be due to patient immobility, improved accuracy of mapping, and catheter stability. Immobility and reduced thoracic excursion may improve contact between the catheter and the endocardium, optimizing lesion...
quality, Fluoroscopy time and procedure time were also shorter in the GA group.

It has been suggested that jet ventilation would further improve catheter stability. General anaesthesia may be associated with fewer complications of the procedure and has the benefit of there being a second experienced clinician in the catheter laboratory in the event of a complication.

Moreover, patients seem to prefer general anaesthesia: a prospective non-randomized questionnaire study carried out in my institution questioned 38 GA patients and 120 patients who had undergone AF ablation under local anaesthesia and sedation. Post-procedural pain was similar in both groups; however, 67% of the GA patients rated the experience as excellent compared with 52% of the patients overall. Patients who had had a second ablation under general anaesthesia (after a first procedure under sedation) all commented that they preferred the general anaesthetic procedure.9

**Recovery**

Anaesthetic recovery facilities are frequently inadequate or non-existent in the catheter laboratory suite. This requires locally devised solutions, but trained recovery staff and appropriate monitoring are mandatory after prolonged general anaesthesia. A post-operative TOE before extubation can exclude a pericardial effusion. Alternatively, a transthoracic echo can be performed in recovery. Pain is controlled with local anaesthetic infiltration at the catheter puncture site in the groin and simple oral analgesia. Dyspnoea may be due to a combination of atrial stunning and fluid overload. It should be promptly treated with diuretics.

**Complications**

Catheter ablation of AF has a reported worldwide mortality of 1:1000 procedures.10 This is significant for the treatment of a condition that can be controlled by drug therapy and for a procedure that is undertaken in a predominantly healthy population for symptom control and improved quality of life.11 It also should be noted that the rate of long-term arrhythmia control or cure is ~70%, although this is continually improving. Age over 75 yr and congestive cardiac failure are associated with an increased risk of complications.12

Anaesthetic complications are predictable and amenable to the usual measures. These include hypotension, suppression of the arrhythmia, airway complications, and complications of positioning. Complications attributable to the ablation procedure are more difficult to diagnose and treat. They occur rapidly and may be catastrophic. The complications are shown in Table 1.

Cryo-balloon has specific additional complications. The phrenic nerve is in close proximity to the right upper pulmonary vein (RUPV). The risk of phrenic nerve palsy during RUPV ablation is mitigated by pacing the phrenic nerve and observing diaphragmatic contraction. For this reason, the patient must not be paralysed during this part of the procedure. Pulmonary vein stenosis can also occur with cryo-balloon ablation. This is more frequent if the smaller 23 mm balloons are used compared with the larger 28 mm balloons.

**Conclusion**

As cardiac surgery becomes less invasive and percutaneous interventions continue to develop, cardiac anaesthetists will spend more time in the catheter laboratory environment. The principles of anaesthesia in the cardiac catheter laboratory will be similar and transgress many different catheter-based techniques. It is important that we understand the new technologies and demands of a particular procedure so that we can continue to develop and deliver a high-quality cardiac anaesthetic service for the future. This has significant implications for service provision in cardiac anaesthetic departments.

**Declaration of interest**

None declared.

**References**

1. Central Cardiology Audit Database. www.ccad.org.uk

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**Table 1** Complications of catheter ablation procedures grouped into categories related to stages of the procedure

<table>
<thead>
<tr>
<th>Complications</th>
<th>Consequences</th>
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<tbody>
<tr>
<td>Vascular complications of arterial and venous puncture</td>
<td>Retroperitoneal bleeding</td>
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<tr>
<td>Vascular complications of transseptal puncture</td>
<td>Atrial perforation</td>
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<tr>
<td>Complications of transseptal puncture</td>
<td>Aortic perforation</td>
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<tr>
<td>Complications of transseptal puncture</td>
<td>Pericardial effusion</td>
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<tr>
<td>Complications of transseptal puncture</td>
<td>Cardiac tamponade</td>
</tr>
<tr>
<td>Complications of left atrial ablation</td>
<td>New intra-atrial shunting</td>
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<tr>
<td>Arrhythmias</td>
<td>Mitral valve damage</td>
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<tr>
<td>Arrhythmias</td>
<td>Pulmonary vein stenosis</td>
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<tr>
<td>Arrhythmias</td>
<td>Coronary obstruction</td>
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<tr>
<td>Arrhythmias</td>
<td>Atrial and ventricular arrhythmias</td>
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<tr>
<td>Arrhythmias</td>
<td>Bundle branch block</td>
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<tr>
<td>Arrhythmias</td>
<td>Complete heart block (AVNRT ablation)</td>
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<tr>
<td>Oesophageal damage due to thermal injury</td>
<td>Oesophageal perforation</td>
</tr>
<tr>
<td>Oesophageal damage due to thermal injury</td>
<td>Atrial-oesophageal fistula</td>
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<tr>
<td>Thoracic nerve injury</td>
<td>Vagal nerve injury causing acute pyloric spasm</td>
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<td>Thoracic nerve injury</td>
<td>and gastric hypomobility</td>
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<tr>
<td>Thoracic nerve injury</td>
<td>Left recurrent laryngeal nerve palsy</td>
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<tr>
<td>Embolic complications due to clot or air</td>
<td>Stroke</td>
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<tr>
<td>Embolic complications due to clot or air</td>
<td>Transient ischaemic attack</td>
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<tr>
<td>Embolic complications due to clot or air</td>
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<td>Embolic complications due to clot or air</td>
<td>Fluid retention</td>
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<td>Pulmonary oedema</td>
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<td>Enocardiitis</td>
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<td>Atrial stunning</td>
<td>Skin burns at electrodes on patients back</td>
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<tr>
<td>Infection</td>
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<td>Burns</td>
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Please see multiple choice questions 5–8.