Anaesthesia in the cardiac catheterization laboratory

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Learning objectives

After reading this article, you should be able to:

- list the challenges associated with delivering anaesthesia to patients in cardiac catheterization laboratory (cath lab)
- describe the concept of common cardiological procedures
- discuss the merits of different modes of anaesthesia for cardiology procedures
- formulate an anaesthetic plan for routine cath lab procedures, taking into account specific requirements for a given procedure

Abstract

Anaesthetists play a key role in the management of patients in the cardiac catheterization laboratory (cath lab), both for elective and emergency procedures. Safe and effective provision of anaesthesia relies on a thorough appreciation of the setup of the cath lab and an understanding of the ever-increasing range of procedures carried out in the angiography suite. This article provides an overview of general considerations for working in this challenging environment within the hospital, as well as outlining key cardiology subspecialties and their requisites for the anaesthetist: electrophysiology, structural, interventional, devices and mechanical circulatory support.

Keywords Anaesthesia; cardiac catheterization; cardiac electrophysiology; cardiology; coronary angiography; sedation; structural cardiology

Royal College of Anaesthetists CPD Skills Framework: Cardiothoracic, anaesthesia for radiology

Introduction

The anaesthetic requirements in a cardiac catheterization laboratory (cath lab) include all those of non-operating room anaesthesia, but include several unique considerations: nearly all patients have varying degrees of underlying cardiovascular pathology; a procedural complication may require urgent cardiothoracic surgical intervention; and emergency patients may arrive in extremis for a highly time-critical procedure, where there needs to be balance between taking time taken to stabilize and proceeding with the life-saving coronary intervention.

In addition, interventional cardiology is rapidly evolving with multiple novel techniques that have new and sometimes unknown anaesthetic concerns and possible complications. There are more than 300,000 cardiac cath lab procedures per year in the UK.

Teamwork is a key element of a successful patient experience, and along with the anaesthetist, operating department practitioner (ODP), cardiologist and nurse, key team members here include electrophysiologists, radiographers, and technicians for new devices. Understanding the role each person plays and active communication is essential.

As technology and experience develops, so does the range of procedures performed within the cardiology angiography suite. The anaesthetist's role within the cath lab has also changed due to the increase of nurse-led sedation and as a reflection of refinement of procedures to the point where general anaesthesia (GA) or deep sedation may no longer be essential. Despite this most centres will still provide 'GA lists' for cath lab for procedures and/or patients that may be more complex.

This article aims to give an overview of GA considerations for cases in the cardiac catheterization laboratory as well some specific considerations for subspecialized procedures. The authors do not intend for this to be an exhaustive review of the entire spectrum of procedures taking place in cath lab as this is a continuously evolving field with practice varying from centre to centre.

General considerations

Standard practices for non-operating room anaesthesia apply, such as an established pathway for help in a remote location, accounting for the time for help to arrive, and designating emergency leads for assistance.

Pre-assessment

Patients for cath lab procedures seldom visit pre-anaesthetic clinics, but all patients are effectively seen by cardiology before anaesthesia. This does not leave much room for pre-optimization, but it does emphasize the need for a thorough anaesthetic history and examination. Investigations are usually tailored to the presenting complaint, not with anaesthesia in mind.

Important focus points of the history include exercise tolerance, the ability to lie flat, advanced directives, anticoagulant use, contraindications to transoesophageal echocardiography (TOE), previous anaesthesia, and patient preference for type of anaesthesia. Examination should include a careful airway assessment, as equipment and senior backup need to arranged beforehand. An assessment should be made for signs of heart failure, pulmonary hypertension, and rhythm disturbances. It is helpful to review recent ECGs which are often available and

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assess for dynamic changes. Medication review is important, and an individualized decision should be made on continuation or stopping of any drug.

Ergonomics

The ergonomics of the room are set up to maximize the cardiologist's comfort; coupled with additional cardiac monitoring equipment, large display screens, the anaesthetic machine, intravenous (IV) stands, and moving fluoroscopy C-arms, there is often not much space for the anaesthesiologist to have patient access and monitor visibility. Figure 1 illustrates a typical cath lab setup. Careful planning is required before the procedure begins, so that all the teams are unconstrained.

Some cath labs do have dedicated anaesthetic rooms, but most will at least have an anaesthetic cupboard or trolley containing drugs and consumables required for standard anaesthesia. Additional equipment may not be immediately available, so equipment requests and plans for anticipated difficulties should be communicated to the team in advance.

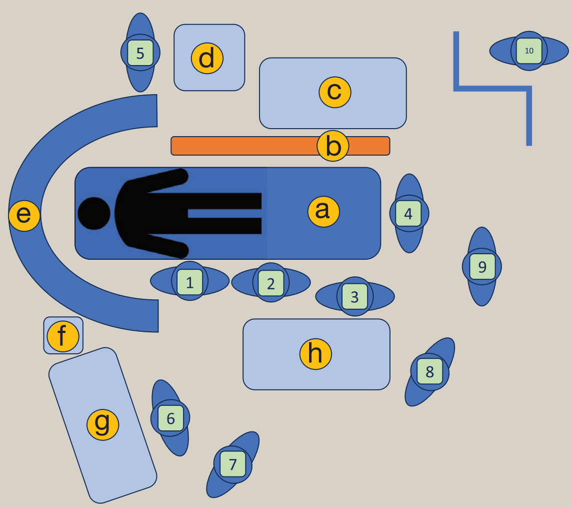
Team members

Cath lab procedures involve a wide and varied team comprising numerous different staff groups:

- Cardiology — often two operators, perform the procedure
- TOE sonographer — this role may be performed by the anaesthetist
- Radiographer
- Cardiac physiologist — involved with electrophysiological (EP) mapping, pacing devices, and mechanical support
- Cath lab nurses — scrubbed and circulating
- Anaesthetist
- Anaesthetic nurse/ODP
- Industry reps — provide training and information on novel devices and techniques.

The majority of cath lab procedures take place without anaesthetic support, under local anaesthesia and nurse-led sedation. The team may be less familiar with considerations for GA and potential risks; this should be taken into account by anaesthetists, particularly in the event of an emergency.

Schematic diagram showing positioning of staff (numbered) and equipment (lettered) around the patient in the cath lab



1: Primary operator; 2: Secondary operator; 3: Scrub nurse; 4: Radiographer; 5: Echosonographer; 6: Anaesthetist; 7: Anaesthetic nurse operating department practitioner/operating department assistant; 8: Circulating nurse; 9: Industry rep; 10: Physiologist (often in control room with microphone link). (a): fluoroscopy table; (b): Digital display; (c): Equipment trolley (defibrillator, ablation devices etc); (d): Echocardiography machine; (e): Fluoroscopy arm; (f): Drip stand and infusion pumps; (g): Anaesthetic machine; (h): Procedure trolley.

Figure 1

Patient positioning

Patient positioning is also limited as the procedure bed is flat and can usually only be raised or lowered, with no head-up articulation of the table. Some tables may allow for Trendelenburg or reverse-Trendelenburg tilt. Table controls are usually operated by the radiographer. The arms will usually be positioned at the patient's sides but may need to be above the head if bi-plane imaging is required; vascular access must be planned accordingly. In many instances, the venous sheath and/or arterial access by the cardiologist can be 'borrowed' by the anaesthetic team if required.

Radiation

Radiation requires the use of lead aprons and thyroid shields by all staff. Mobile lead screens should also be available. Cath labs must be avoided by pregnant staff members where possible, but this is not always an option. Each staff member will need a specific occupational health assessment of the risks of ionizing radiation exposure. A safe distance should be maintained whenever possible, as the quantity of radiation reduces exponentially with distance; however, the head end is inevitably closer to the X-ray source, and proximity increases if making any adjustment to the patient. IV extensions should be used with the administration port away from the patient. If the anaesthetist needs to spend prolonged time at the head end (for example during airway intervention), radiation should be paused to reduce exposure to the anaesthetist. Radiation badges should be worn by staff who are regularly exposed to ionizing radiation.

Choice of anaesthetic technique

The choice of anaesthesia is patient and procedure dependent, and include GA, deep sedation, monitored anaesthesia care, regional anaesthesia, and local anaesthesia. Cath lab procedures are often of low stimulation but with occasional sharp increases (e.g. ablation, DC cardioversion, tunnelling). As such, patients may be kept in a lighter plane of anaesthesia although careful attention must be paid to the procedure in order to anticipate and manipulate anaesthesia accordingly to avoid patient movement or laryngospasm.

Vascular access

The patient will often be positioned with arms at their sides and not easily accessible once the procedure is underway, with the operators on one side of the patient and the large screen further hampering access. Appropriate venous and/or arterial access should thus be secured prior to draping with consideration given to the potential for cardiovascular instability and major haemorrhage, as obtaining arterial or large bore IV in the event of emergency is likely to be difficult. For certain cases where the cardiologists have arterial access, a pressure line may be transduced to provide blood pressure monitoring. Similarly, a venous sheath placed by the operator may allow additional IV access and can usually be achieved rapidly if needed. Arterial pressure monitoring is not always required and should be considered on a case-by-case basis.

Airway

Choice of airway will be influenced by patient characteristics, but the type and length of procedure should also be considered, along with the limited access to the patient during procedures. Endotracheal tube and supraglottic airway are both appropriate choices for most elective cath lab procedures. In some instances, such as anticipated difficult airway, obesity, or cardiovascular instability, anaesthesia and intubation may need to be carried out on an adjustable patient trolley and the patient subsequently transferred on to the table thereafter. The selected airway device needs to be secured adequately as access to the patient's head will be limited by the C-arm, frustrating any airway intervention.

Sedation versus general anaesthesia (GA)

This is a multifactorial decision but patient characteristics, patient choice, procedure, and the operator's level of experience and preference must be considered. As procedures become more familiar, the need for GA may lessen but this remains operator dependent. Sedation with bolus medications or infusions is often appropriate and well tolerated. Longer procedures requiring the patient to be immobile for extended periods (e.g. EP ablations) may be preferable under GA.

Total intravenous anaesthesia versus volatile

This is largely at the discretion of the anaesthetist. There is some historical evidence that isoflurane may suppress ventricular arrhythmia which would be unfavourable during ventricular ablation procedures, however the benefits of this are probably marginal. Remifentanil and metaraminol infusions may be used to aid delivery of a stable anaesthesia.

Analgesia

Local anaesthetic will be infiltrated at puncture and incisional sites by the cardiologist but may still be uncomfortable at the time of insertion for awake patients. The pain from more stimulating parts of procedures – ablation, tunnelling, cardioversion – is often short lived and simple analgesia will usually suffice.

Heparin

Structural and EP procedures often require systemic heparinization with a target activated clotting time (ACT) of 250–300 seconds. This may be achieved by heparin boluses of 100–200 units/kg and/or infusion by the anaesthetist, or direct administration by the operator. Methods for maintaining an appropriate ACT vary by centre and operator so this should be discussed prior to each case. ACT should be monitored regularly, and a dose of protamine may be requested at the end of the procedure by the operator, often at a reduced dose (50 mg) than would be required for full heparin reversal (10 mg protamine per 1000 units heparin).

Fluids

Unless there is significant bleeding, large volumes of fluid are not usually required, although limited access to IV cannulas results in dead space of infusion lines which must be overcome to ensure bolus drug delivery. Indeed, with infusion of contrast and often significant volumes of fluid administered by ablation catheter systems to irrigate and cool the target area, the patient may receive 500–1000 ml fluid from the procedure itself, before accounting for any fluids administered by the anaesthetist.

Complications

While procedures in the angiography suite are largely safe and well tolerated, they remain potentially high risk for complications:

Tamponade: is a serious complication of any cardiological procedure and warrants a high index of suspicion. Blood pressure monitoring and close availability of echocardiography are essential for the prompt diagnosis of enlarging pericardial effusion and developing cardiac tamponade. The cardiologist may elect to perform pericardiocentesis with or without insertion of a drain. If there is significant or ongoing fresh bleeding into the pericardium, consideration may be given to reinfusion of aspirated blood or processing with cell salvage if available. In the event of uncontrolled haemorrhage, emergency referral to cardiac surgery must occur with a view to emergency sternotomy in the angiography suite or, if stability allows the operating theatre.

Arrhythmia: cardiology patients most at risk of arrhythmia (emergency percutaneous coronary intervention (PCI) and EP interventions) will likely have defibrillation pads in situ, facilitating prompt delivery of electrical therapies. Sedation may need to be increased or converted promptly to GA to facilitate this.

Femoral access issues and retroperitoneal haemorrhage: procedures requiring femoral access carry the risk of bleeding from the puncture site and subsequent retroperitoneal bleeding. Manual pressure, sutures and puncture closure devices may be utilized in combination, but the patient must be nursed as flat as possible in the early post-procedure phase. Post-procedure, patients need careful monitoring to allow prompt recognition and management of haemorrhage. (The radial artery may also be injured but due to its more superficial anatomy, is more easily accessed and compressed compared with the femoral vessels.)

Cardiac failure: fluoroscopy procedures require patients to remain in the supine position. Lying flat during a procedure may cause patients with reduced ventricular function to decompensate into pulmonary oedema.

Human factors

The challenge of delivering anaesthesia in a location remote from theatre, with an unfamiliar team in an environment not designed for the anaesthetist can significantly add to the cognitive load, especially in a pressured or emergency scenario.

Cath lab staff may be preparing for the case during induction of anaesthesia and may lack a full understanding and awareness of conduct of anaesthesia. It is reasonable to ask for quiet and calm in the cath lab during induction, both for patient experience and ease of communication in the event of difficulty. Cath lab staff will be familiar with high-pressure situations and may be utilized in the event of emergency to source resuscitation drugs and equipment, summon help and perform cardiopulmonary resuscitation (CPR) and defibrillation.

The complex nature of cardiological procedures also means that cardiologists may become very task focussed at certain points, with reduced situational awareness. The anaesthetist and other team members must therefore always remain vigilant for cardiovascular instability, bleeding, and other complications.

Electrophysiology

Many rhythm disturbances such as atrial fibrillation, ventricular tachycardia, heart block and others are amenable to various therapies in the cath lab. Electrophysiology (EP) procedures can take many forms depending on the arrhythmia being investigated and treated and the treatment modality being employed. Advances in catheter technology have allowed for more complex and targeted ablation therapy for arrhythmias.

Anaesthesia is guided by the type and duration of procedure. EP procedures may last several hours, and due to the complex mapping of arrhythmia pathways and high-energy ablation, it is imperative for the patient to remain still. Procedures may consist largely of periods of low stimulation with occasional painful stimuli, for example during ablation or defibrillation/cardioversion. For patients with symptomatic arrhythmias, arterial blood pressure monitoring may be prudent as the EP team seek to intentionally provoke arrhythmias, eliciting potential haemodynamic instability.

Sedation may be appropriate for some procedures, although patients should be closely monitored; triggered arrhythmias may cause palpitations, hypotension, anxiety, discomfort, chest pain and diaphoresis. Conscious sedation may also aid with certain procedures by facilitating discussion of stressors in the patient's life which may aid in triggering the arrhythmia in question.

Left atrial appendage (LAA) occlusion

The disordered atrial wall contraction in atrial fibrillation (AF) leads to turbulent flow and stasis of blood, forming a thrombogenic environment. If this happens in the left heart, the potential for systemic emboli can have devastating consequences. The LAA forms a pocket anteriorly where a clot can easily form. A device can be deployed percutaneously to plug this entirely, thus reducing risk; this is especially useful when oral anticoagulation is contraindicated.

The procedure is usually carried out under GA. A TOE is done before and after the procedure to rule out thrombi. Procedural complications include cardiac tamponade, pericarditis, systemic air embolism, device slippage and embolism and arrhythmias.

Ablation of arrhythmogenic pathways

Using various energy sources (radiofrequency, cryoablation, ultrasound, laser and pulsed field), the endocardium can be intentionally scarred in specific patterns to prevent the electrical conduction of pathological rhythms.

For AF this most often includes mapping and ablation of the left atrium (LA) and particularly the pulmonary veins. AF ablations are usually performed via a venous approach and involve a trans-septal puncture across the inter-atrial septum to access the left atrium. This is performed under dual angiographic and TOE guidance. As the latter is often performed by the anaesthetist in cardiothoracic centres it is vital that informed consent is obtained and noted in the anaesthetic record.

Septal puncture is a commonly performed procedure but carries the risk of myocardial perforation and tamponade and so must be carried out under close image guidance. Once the puncture needle has passed through the septum, a sheath will be railroaded across and left in the LA for the procedure. A repeat assessment for pericardial effusion should be performed post-puncture and at the end of the case. A high index of suspicion for cardiac tamponade should be maintained the event of cardiovascular instability.

Where TOE is used, a brief and focused examination should be performed to look at biventricular function, valve function, presence, and size of a pericardial effusion and to screen for a thrombus in the LAA. AF patients will usually be on direct oral anticoagulant (DOAC) therapy and the team should confirm that there have been no missed doses. Despite the anticoagulation, TOE assessment of the LAA is essential due to the intentional triggering of arrhythmia, the potential need to pace at an elevated heart rate, and the risk of requiring cardioversion during the case, all of which may cause an LAA thrombus to embolize.

Diaphragmatic pacing may be performed during AF ablation to monitor the phrenic nerves. The right phrenic nerve sits near the superior vena cava (SVC) and right sided pulmonary veins and as such is vulnerable to injury during ablations in this area. The phrenic nerve is paced via the SVC or subclavian vein and diaphragmatic capture is observed; any reduction or loss of diaphragmatic contraction would signal injury to the phrenic nerve and ablation therapy at that location should stop immediately. If this technique is to be used, the cardiologist should communicate the decision to the anaesthetist who can then ensure that there is no ongoing neuromuscular blockade at the time of diaphragmatic pacing. The technique for avoiding or reversing paralysis would be at the discretion of the anaesthetist. This is particularly important when using cryoablation techniques.

In addition, when using other ablation modalities, dedicated multisite oesophageal temperature probes may avert oesophageal thermal injury. If used, it is best to avoid nasopharyngeal access lest epistaxis ensues. Alternatively pulsed field ablation may be deployed. This targets specific cardiac cells with electrical pulses causing nonthermal irreversible electroporation to induce cell death.

Interventional cardiology

Coronary angiography and PCI are commonly performed, well-practised procedures used in the investigation and treatment of coronary artery disease. Diagnostic procedures are mostly performed using right radial arterial access; the cardiologist will advance a long catheter up to the aortic root and inject dye into each coronary ostia to perform a coronary angiogram. Based on findings, coronary intervention may be required, taking the form of balloon angioplasty (expansion of a balloon to open a narrowed coronary artery) or placement of a stent to open and maintain patency. Coronary interventions often require femoral artery access also. Rotablation is an emerging new technique where a catheter-mounted burr is used to grind away calcified coronary plaques prior to balloon angioplasty and or stent placement. Rotablation procedures are often complex and prolonged, especially in the treatment of chronic total occlusion (CTO) of major coronary arteries and as such often requires general anaesthesia.

Emergency PCI

Patients are often brought directly to the cath lab by paramedic teams as part of 'primary' PCI pathways. These cases usually proceed without the involvement of anaesthesia, although anaesthetic support may be requested in the event of cardiovascular instability, neurological impairment or if the patient has been intubated by pre-hospital teams. The anaesthetic team may be called prior to the arrival of a shocked or intubated patient, or mid-procedure for a deteriorating patient.

In all primary PCI cases the adage of "time is muscle" rings true, and while basic principles of resuscitation and ABC management must be followed, an emphasis must also be placed concurrently on reducing the time from patient arrival to commencement of PCI. Some patients may present in extremis, potentially with mechanical CPR devices in situ such as the LUCAS (Stryker, Portage, MI, USA) or Autopulse (ZOLL, Chelmsford, MA, USA). The team should endeavour to reduce interruptions to CPR during patient transfer. Intravenous or intraosseous access will usually have been inserted prior to arrival.

If a definitive airway is required, a cardiostable induction of anaesthesia should be performed with prompt transfer on to the angiography table. Arterial access by the cardiologists for PCI will allow for continuous blood pressure monitoring so PCI should not be delayed for the placement of a dedicated arterial cannula for monitoring. The arterial sheath will be connected to the monitor used by the cardiology and physiology teams so may not be easily viewable by the anaesthetist. If this is the case, the use of the sheath for monitoring should be discussed with the team to develop a shared mental model and ensure that any cardiovascular instability is communicated clearly. Defibrillation pads should be pre-emptively applied and connected to the defibrillator.

Cardiovascular instability and arrhythmia may occur at any point during emergency PCI, but are especially likely during the temporary occlusion of vessels that occurs with balloon inflation for angioplasty and stent deployment, or during reperfusion of an acutely occluded vessel. A central venous line may be required post-procedure if the patient remains unstable.

In the event of out of hospital cardiac arrest or collapse, further investigations may be required prior to transfer to coronary care/high-dependency unit/intensive care unit, particularly in the absence of an obvious coronary cause of presentation. CT head to rule out intracerebral haemorrhage, and CT chest to assess for dissection or pulmonary embolism may be considered based on history and examination.

Cardiogenic shock

Emergency PCI patients with low blood pressure, signs of low cardiac output and evidence ventricular impairment on transthoracic echocardiography should be assessed and reassessed for cardiogenic shock. The Society for Cardiovascular Angiography & Interventions (SCAI) stages of cardiogenic shock aid recognition, assessment and management of cardiogenic shock (Table 1).

Effective management of cardiogenic shock centres around timely diagnosis, evaluation of severity, prompt use of inotropes and/or vasopressors, and early escalation for extracorporeal membrane oxygenation (ECMO) consideration, often using a multidisciplinary team 'shock call' approach.

Elective PCI

Elective coronary angiography and intervention is very commonly performed procedure, most frequently carried out under local anaesthesia with or without nurse-led sedation using bolus IV short-acting sedatives such as midazolam. If there are no complications, anaesthesia services are seldom required. The anaesthetist may be called to these procedures if there has been a procedural complication such as coronary artery rupture, tamponade, cardiac arrest, delirium, or any other patient-related complication.

As techniques, experience and technology develop, interventional cardiologists can take on more challenging cases in higher risk individuals than were previously attempted. While coronary angiography and intervention itself remains a minimally invasive procedure, the increasing complexity of cases results in the potential for serious complications and subsequent deterioration, which may require the skills of anaesthetists and intensivists for ongoing management.

Society for Cardiovascular Angiography & Interventions (SCAI) stages of cardiogenic shock

SCAI Classification	Stage	Description
A	At risk	No symptoms of cardiogenic shock but at risk of developing, seen in acute myocardial infarction, chronic cardiac failure
B	Beginning	Clinical evidence of hypotension or tachycardia without hypoperfusion
C	Classic	Patient manifesting hypoperfusion requiring pharmacological or mechanical circulatory support (beyond fluids)
D	Deteriorating	Similar to C but failing to respond to therapies
E	Extremis	Circulatory collapse, ± refractory cardiac arrest, requiring multiple simultaneous acute interventions due to lack of clinical stability

Table 1

Structural cardiology

Structural cardiology procedures have developed significantly over the last decade, and while there are many procedures and variations being performed in centres worldwide, in this article we will focus on the more commonly performed procedures.

Transcatheter aortic valve intervention/replacement (TAVI/R)

This is a procedure whereby the aortic valve is replaced by the insertion of a bioprosthetic implant, delivered by an arterial catheter (most commonly femoral). TAVI is generally reserved for older, more unwell patients with stenotic aortic valve disease who may not be considered good candidates for surgical aortic valve replacement. A guide wire is advanced via the femoral artery, retrograde up the aorta, around the arch, through the aortic valve until its tip sits in the left ventricle (LV). The stenotic valve is initially treated with a balloon aortic valvotomy (BAV) to open up the valve and free restricted cusps. The TAVI valve is then advanced over the guidewire and is positioned appropriately across the native aortic valve using fluoroscopy. As the balloon-expandable or self-opening valve is deployed (Figure 2), the LV is rapidly paced via the guidewire to temporarily reduce flow of blood from the LV to the aorta. Once satisfactorily positioned, the guidewire and deployment apparatus are removed, leaving the new valve in situ.

TAVI may be carried out with additional procedures such as PCI and in high-risk patients, may be supported by temporary Impella insertion (described later). Aside from standard complications, there are specific risks associated with TAVI (Table 2).

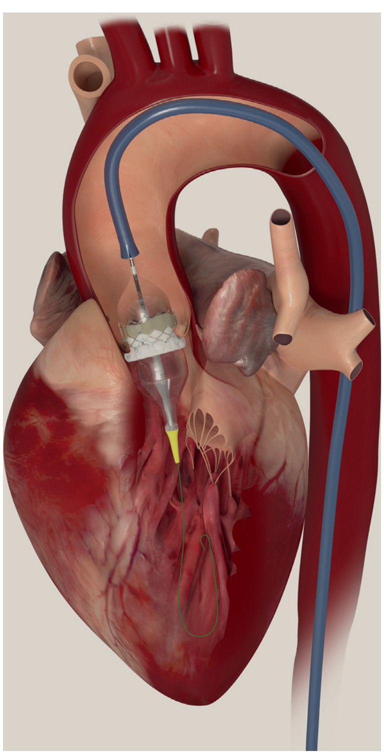


Figure 2 Deployment of a balloon-expandable Sapien 3 TAVI valve (Edwards Lifesciences, Irvine, CA, USA). The left ventricle can be rapidly paced using the green guidewire during balloon expansion of the valve in the aortic position. Figure courtesy of Edwards Lifesciences.

In the early days of TAVI, patients were often fully anaesthetized with arterial and central venous access and procedures performed in a hybrid operating theatre with surgeons on standby in the room to handle complications. Over time the surgical presence has been scaled back to offer ‘on call’ cover for TAVI, while GA has been replaced largely with monitored sedation.

The choice of anaesthesia is guided by the patient, their co-morbidities (often multiple in elderly patients undergoing TAVI) and any additional procedures. In many cases intermittent bolus sedation or single agent infusions will suffice. Blood pressure can be monitored using the cardiologists’ arterial sheath and fluid line extensions can be connected to the venous sheath in case of bleeding.

While originally reserved for patients who were not deemed surgical candidates, the positive outcomes have led to the expansion of inclusion criteria for consideration for TAVI. This means that younger fitter patients may be offered TAVI, but also that more elderly and complex patients are being considered for the procedure.

Current studies suggest a valve lifetime of around 8 years following TAVI. Redo TAVI (often called TAVI in TAVI) is an increasingly commonly performed procedure and TAVI may also be performed within a surgically implanted bioprosthetic aortic valve replacement.

Transcatheter edge-to-edge repair (TEER)

TEER is a term used to describe various percutaneous treatments for regurgitation, primarily in the mitral valve but increasingly in the tricuspid valve. Rather than replacing the mitral valve, a device such as a MitraClip (Abbott, Santa Clara, CA) is used to fix portions of the anterior and posterior mitral valve leaflets together. This creates two smaller mitral orifices for blood to pass through while reducing mitral regurgitation (Figure 3). There are various novel percutaneous valve therapies in various stages of development and use (including TAVI valves in the mitral position), but they are beyond the scope of this article.

PFO closure

Percutaneous patent foramen ovale (PFO) closure may be performed in patients with a history of stroke/transient ischaemic attack in the presence of a PFO. The procedure is performed using a catheter-deployed occluder. Under fluoroscopic and echocardiography guidance (transoesophageal or intracardiac echocardiography), a guidewire via the femoral vein is advanced up into the right atrium (RA) and across the PFO into the left atrium (LA). The LA portion of the butterfly-shaped occluder is deployed and the device pulled back gently to ensure a tight fit to the inter-atrial septum, before the RA side of the device is deployed, completing the procedure (Figure 4). While this procedure does not involve *de novo* septal puncture, the passage of a guidewire and sheath across the heart does involve some risk of myocardial injury and potential tamponade. Patients undergoing this procedure are likely to be on antiplatelet and/or anticoagulation agents so are at increased risk of bleeding from puncture sites.

Devices

Cardiac devices may be implanted for a wide range of indications including inherited conditions, complications of ischaemic heart

Recognized transcatheter aortic valve intervention (TAVI) complications and their management

Complication	Occurrence rate	Management
Bradycardia and arrhythmia due to compression of the conduction system	5–10%[a]	Permanent pacemaker, antiarrhythmic medications
Stroke and risk of embolization of calcified plaque during the procedure	CVA risk 3%	Mechanical thrombectomy may be considered. If anticipated, cerebral embolic protection devices available to temporarily deploy in the aortic arch to protect the arch vessels from the embolic material.
Femoral vessel injury and retroperitoneal haemorrhage	5%	Covered stent insertion. Vascular surgical repair.
Paravalvular leak (PVL)	5%[a]	Small PVLs are acceptable but moderate to severe leaks may require further procedures to avoid symptoms
Occlusion of coronary ostia	<1%	Can be mitigated by a BASILICA[b] procedure whereby the offending leaflet is split to allow blood flow into the ostia

[a] More commonly seen in self-expanding TAVI valves.
[b] Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Iatrogenic coronary artery obstruction during TAVR.

Table 2

disease and post-cardiac surgery. Devices include pacemakers (PPM), implantable cardiac defibrillators (ICD), cardiac resynchronization therapy devices (pacing alone – CRT-P, with defibrillation therapies – CRT-D) and long-term rhythm monitoring devices (Reveal). Subcutaneous ICDs (S-ICD) are gaining popularity and leadless PPMs are also implanted in cath lab.

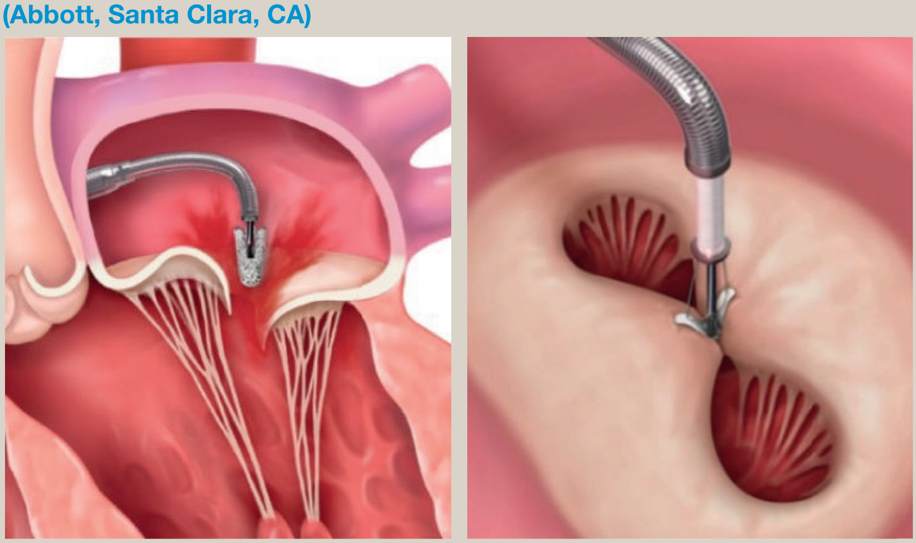
Most device implantations are well-tolerated with infiltration of local anaesthetic by the cardiologist. Sedation or anaesthesia may be indicated for challenging patients (e.g. patient preference, anxious patients, or those with learning difficulties), subpectoral device implantation and revision, S-ICD insertion, and more complex lead revisions and lead extraction.

Anaesthetic considerations

For the majority of first-time device implantations, the device will be inserted on the patient's non-dominant side. As the procedure will involve puncture of venous structures, it is advisable to obtain venous access on the *contralateral* side. In order to assess venous patency (often in the presence of pre-existing wires) a venogram may be required, for which an additional peripheral intravenous cannula on the *ipsilateral* side would be necessary for administering contrast.

Intra-arterial blood pressure monitoring is not usually required, although should be considered patients with severe

Insertion of MitraClip trans-catheter edge-to-edge repair(TEER) device (Abbott, Santa Clara, CA)



Following a septal puncture, the device is deployed, approximating the anterior and posterior mitral valve leaflets as a treatment for mitral regurgitation, forming two small mitral orifices. Reproduced with permission of Abbott, © 2023. All rights reserved.

Figure 3

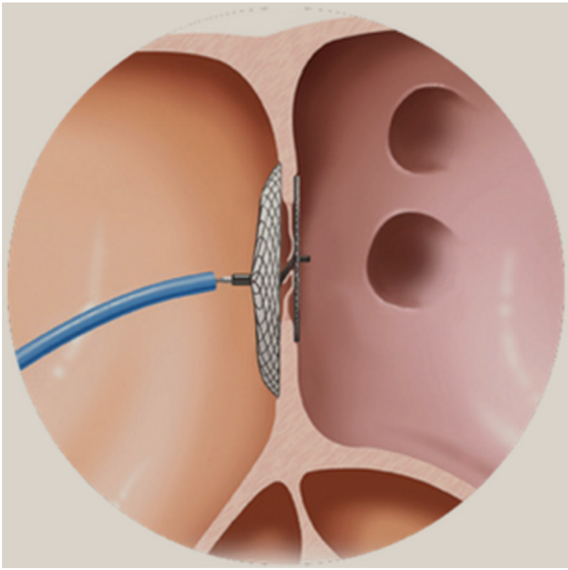


Figure 4 Amplatzer septal occluder (Abbott, Santa Clara, CA). The delivery cable is passed under transoesophageal echocardiography and fluoroscopic guidance through the patent foramen ovale. The left atrial disc is expanded first, pulled back flush to the inter-atrial septum and then the right atrial disc is expanded. Reproduced with permission of Abbott, © 2023. All rights reserved.

heart failure (often the case for CRT device insertions) or other significant co-morbidities.

S-ICD

Subcutaneous ICDs (Boston Scientific) are being implanted in increasing numbers for patients who have personal or strong family history of potentially fatal arrhythmias but do not require pacing. A pulse generator is implanted subcutaneously on the left lateral aspect of the chest below the axilla. An electrode is then tunnelled under the skin across the anterior chest reaching just lateral to the sternum superiorly, allowing an arrhythmia to be detected and an electrical shock to be delivered across the heart if required (Figure 5). The device can also pace for a short period following a delivered shock in the event of severe bradycardia.

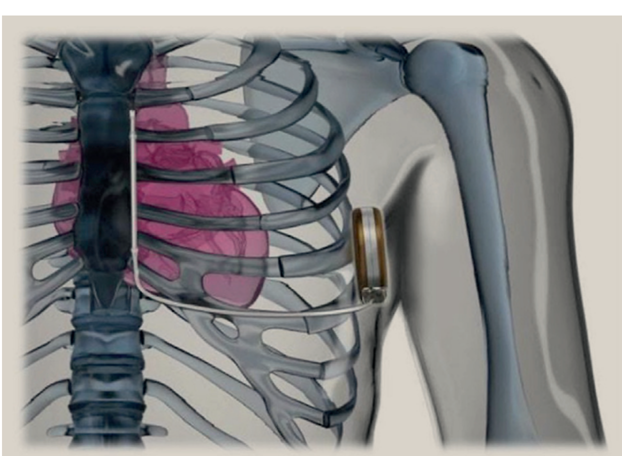


Figure 5 S-ICD (Boston Scientific, Marlborough, MA, USA) demonstrating impulse generator in sub-axillary region and position of tunnelled electrode. Image courtesy of Boston Scientific.

GA is often preferred for S-ICD implantation due to the high volumes of local anaesthesia required to cover the involved areas. Tunnelling close to the sternum can also be very painful, particularly if the periosteum is traumatized. Sedation with or without serratus anterior block has also been described. Following implantation, ventricular fibrillation (VF) is induced by application of a DC current across the heart, and the S-ICD is allowed to sense the VF and deliver up to two shocks in quick succession. If the S-ICD fails to shock the patient out of VF, conventional defibrillation via in situ external pads will be delivered. This testing process should be considered when planning the mode of anaesthesia or sedation for patient comfort both during induction of VF and defibrillation.

Lead extraction

Existing leads may be removed from patients in the event of chronic lead infection or lead failure or fracture. While leads may be removed easily with simple traction, leads with a long duration in situ (pacemaker lead >15 years, ICD >10 years) are higher risk and may require more complex procedures using cutting sheaths or laser catheters. These complex procedures may still be performed under local anaesthesia, but higher risk cases require careful planning and preparation to mitigate the potential risk of damage to the heart and vascular structures upon lead removal. These are often performed under GA with arterial monitoring and central venous access, in a hybrid theatre with cardiac or vascular surgeons involved or on stand-by.

Mechanical circulatory support

A comprehensive guide to mechanical circulatory support (MCS) is beyond the scope of this article but it is not uncommon for various devices to be utilized in certain emergent or high-risk scenarios in the cath lab.

Intra-aortic balloon pump (IABP)

The IABP is a temporary circulatory support device that is placed via the femoral artery and passes retrograde up the aorta, sitting in the proximal descending thoracic aorta. Attached to a control module, this is a balloon-tipped catheter is placed in patients undergoing high risk PCI or following PCI where there is evidence of acute ventricular impairment.

The balloon is inflated with helium in diastole and deflated during systole. This counter-pulsation aims to:

- increase diastolic coronary blood flow (balloon inflation forces blood retrograde towards the coronaries)
- reduce LV afterload (balloon deflation lowers the aortic resistance to flow)
- provide a small amount of additional forward systemic flow (balloon inflation increases aortic pressure).

The control console allows the trigger source (ECG, pressure, pacing), frequency, level of augmentation and timing of balloon inflation/deflation to be adjusted.

Correct positioning of the IABP is essential and the tip of the catheter should sit just distal to the left subclavian artery (LSA). This can be seen on fluoroscopy (and chest X-ray) with the tip ideally seen at the level of the carina. Malposition can cause intermittent occlusion of head and neck vessels or even the renal arteries. The large size of the control console means that it is

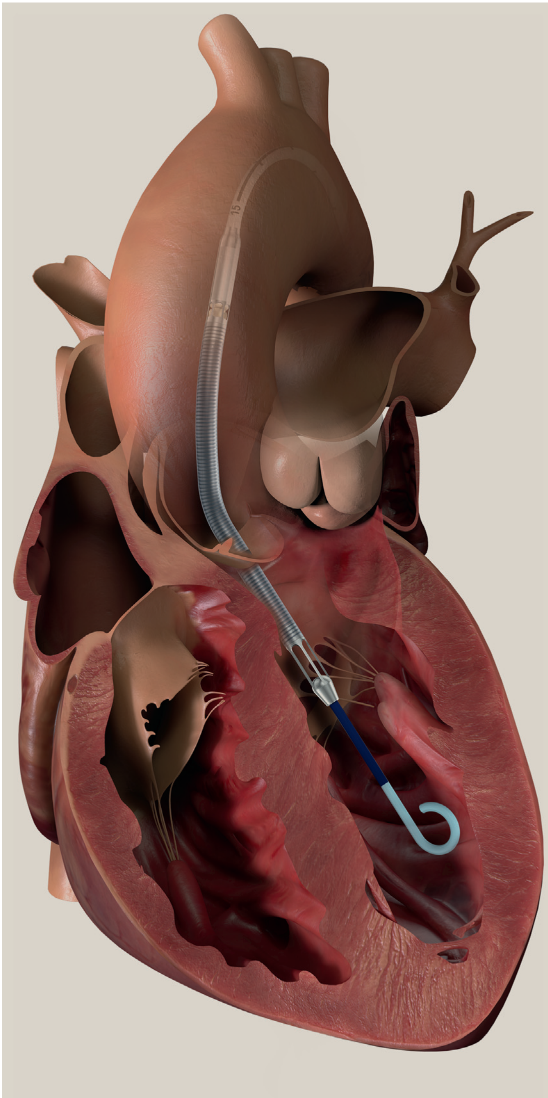


Figure 6 Impella CP device (Abiomed, Danvers, MA, USA) showing the device in situ in the aorta and left ventricle. Blood is sucked into the left ventricle tip of the Impella, through the device and then ejected under pressure into the proximal aorta, supporting the cardiac output. Figure courtesy of Abiomed.

mounted on a cart; when transferring a patient with an IABP, a nominated individual (often the physiologist) should be tasked with moving the console while other team members push the patient trolley/bed, keeping a close distance to prevent displacement or disconnection of the IABP and its tubing.

Impella

Impella devices are a group of temporary ventricular assist devices (VAD) that can be inserted percutaneously to support high risk PCI and manage cardiogenic shock. There are various devices approved for both left and right ventricular support, but of particular interest in cath lab is the Impella CP (Abiomed)—licensed to be used for a duration of 6 hours or less via the axillary artery. The Impella CP can deliver flows of up to 4.3 litres/minute using axial pump technology. The tip of the device is advanced into the LV (Figure 6), where an internal axial rotor pulls in blood, forces the blood along the length of the impella (across the aortic valve) and pushes it out under pressure into the aorta.

Extracorporeal membrane oxygenation

In severe cardiogenic shock with a potentially reversible cause, the decision may be made to establish veno-arterial (VA) ECMO to maintain systemic perfusion. After placing large-bore cannulas under ultrasound guidance into the femoral artery and vein, blood is removed from the venous circulation, passed through a gas-exchange membrane and returned under pressure, retrograde up the aorta to provide systemic perfusion. Fluoroscopy is used to confirm the correct placement of cannulas. Where available, ECMO may be used during emergency PCI as part of E-CPR (extracorporeal cardiopulmonary resuscitation). As there is still blood passing through the lungs, mechanical ventilation should be continued once ECMO is established so that blood ejected from the LV is oxygenated.

Summary

While many cardiology procedures are well tolerated with only local anaesthesia or minimal sedation, the ever-increasing complexity of procedures and patients means that the scope and scale of anaesthetic involvement in the cath lab is likely to increase. Careful patient assessment, clear communication with the entire team, and good understanding of the requirements for each procedure are key to delivering safe, effective anaesthesia in the cath lab. ◆

FURTHER READING

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