New Era of Off-site Catheter Based Procedures and Anesthesia

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Description:

This refresher course lecture will highlight the anesthetic considerations for a variety of interventional cardiology procedure. The concept of the Hybrid OR is a reality in many centers now, and a basic understanding of the types of procedures being done is necessary to provide anesthetic care. This syllabus will provide the background information for the lecture, which will focus on clinical application of anesthesia in these challenging locations.

Introduction:

Interventional Cardiac techniques have evolved well beyond the initial Percutaneous Cardiac interventions done in the late 1970s published by Gruntzig and colleagues [1]. Percutaneous therapy now exists to treat brady or tachyarrhythmias via pacemaker / defibrillator insertion, tachyarrythmias requiring ablative procedures, septal defects amenable to percutaneous device closure, and mitral regurgitation amenable to percutaneous clipping. Additional procedures that are becoming commonplace include lead extractions using a variety of lead extraction techniques and the LARIAT procedure to isolate the atrial appendage in atrial fibrillation. Obviously there are recent advances in percutaneous valve implantation as well, but this will not be covered in this lecture. This summary will break these topics into three main sections: Procedures in the Electrophysiology suite; Procedures in the hybrid OR (Lariat, Laser Lead), and those performed in the Interventional Catheterization Suite (MV clipping, septal defect closure); Anesthetic management recommendations will be presented throughout, with a summary table at the end.

Regardless of the type of intervention being performed, more and more of these patients have significant co-morbid medical conditions warranting close evaluation by the anesthesiologist before the procedure. Many times these patients have incomplete medical records, pending labs, or are actually emergent cases thus the anesthesiologist may have to deal with a very sick patient, in the setting of limited pre-operative information. Patients may present with intra-aortic balloon pumps or percutaneous ventricular assist devices, or have multiple vasopressor infusions in place for hemodynamic support. A general comfort level with these modalities and medications is needed for the anesthesiologist to safely manage and direct the care of these patients.

In general, procedures carried out in off site locations or hybrid suites introduce a unique challenge for the anesthesiologist compared to the standard OR setup. The large amount of imaging equipment such as C-arm fluoroscopy and viewing screens, echocardiography, and unique imaging specific tables creates a setup that is less than ideal for the anesthesiologist. Limited access to the head / airway, along with various layouts to the room adds an additional challenge to these cases. Assessment of each individual location should be considered in planning your anesthetic and airway management strategy so appropriate access can be obtained when the need arrives.

Electrophysiology Suite (EP)

Cardiac Arrhythmias account for >800,000 hospitalizations and > 40,000 deaths annually [2]. To treat these patients, nearly 15,000 pacemaker (PM) devices and 10,000 Implantable Cardioverter Defibrillator (ICD) devices are implanted in the United States each month [3]. However, for more complex tachyarrhythmias, catheter ablation techniques have evolved to allow for improved outcomes for many patients. Catheter ablation procedures are possible for Atrial Fibrillation, Atrial flutter, and Ventricular tachycardia; allowing for better use of cardiac resynchronization therapy [4].

The diagnostic EP study is the cornerstone that all the ablative procedures are based upon. Initially an electroanatomic map (EAM) is created using a 3D reconstruction of the heart combined with color mapping representing electrical conduction pathways. EAM's are reliant on patient positioning and the patient remaining still to allow for accurate guidance of catheters during the ablation procedure[5]. The technique of EAM is well described by Kwak in 2013 [4]. "Color coding is used on the map to show the origin and pattern of signal propagation. Pace mapping involves pacing at a particular site and recording the resultant 12-lead ECG. The goal is to find a pacing site that results in QRS complexes that are identical to those found on a previously obtained 12-lead ECG showing the arrhythmia. Entrainment mapping is used to identify sites within the circuit of reentrant tachycardia such as atrial flutter, atrioventricular nodal reentrant tachycardia, and VT. Information is collected during overdrive pacing at a rate faster than the arrhythmia to find sites within the reentry circuit. Substrate mapping creates a 3D electroanatomic map using ECG amplitude, which corresponds to voltage. Low voltage areas are typically scars or

areas of fibrosis from infarction, surgery, or previous ablation"[4].

The Electrophysiologist obtains vascular access and various catheters are positioned in atria or ventricular chambers, typically via femoral veins, but occasionally via internal jugular or subclavian veins, or even the femoral artery. Programmed pacing is carried out allowing study of the intrinsic conduction system, as well as induction of the pathologic arrhythmia. Right-sided catheters and coronary sinus catheters are done without systemic anticoagulation, but should access to the left side be required for mapping or ablation, then systemic heparinization is needed to prevent embolization. Left sided structures are either accessed using atrial septal puncture or via retrograde aortic access. Mapping is the critical stage of arrhythmia ablation providing the road map for subsequent intervention. **Due to the sensitivity of the conduction system to various sedative agents, mapping is often done under light or even no sedation**. Ventricular arrhythmias have a high sensitivity to local anesthetics as well, and thus for these patients, local anesthetic use is minimized as well. [5]

The ablation procedure itself was initially done with high energy current, but is now typically carried out using radio-frequency ablation or cyro-ablative techniques. Success depends on stable catheter contact with the wall of the heart, thus excessive heart motion tends to impede good contact, and slow the ablative process. Importantly, RF ablations generate significant amounts of heat, and the catheter tip is cooled using saline infusions. This can lead to fluid overload of patients over the course of long ablative procedures, a key point to consider for all ablations.

SVT Ablations:

The most common supraventricular lesions amenable to ablation are AV nodal re-entrant tachycardia, AV re-entrant tachycardia, atrial flutter, and atrial tachycardia. Atrial Fibrillation is also amenable to ablation and will be discussed separately. SVT lesions should be mapped out with minimal sedation. Once the EAM is established, more attention should be placed on patient comfort as the ablation procedure often takes multiple hours. Various levels of sedation may be needed on case-by-case basis, but SVT arrhythmias are induced in part by intrinsic adrenergic tone, thus elimination of this response via anesthetic sedation can make identification and ablation of these lesions difficult. For patients with normal airway anatomy amenable to light conscious sedation, this is the recommended technique for the duration of the ablation. A key point in SVT ablations is that these tend to be fairly hemodynamically stable (in contrast to VT ablations), and thus additional invasive monitors by the anesthesiologist are generally not needed unless the patient has severe concomitant heart disease. General anesthesia may become necessary for patients who have sleep apnea, are morbidly obese, or have other impediments to sedation, but this should be done after the initial mapping. It is critical to avoid patient motion however during the sedation process, as this changes the catheter positions and makes the initial mapping studies less accurate. General anesthetics do appear to impact nodal conduction and ventricular repolarization – however the mechanism is not entirely clear[4]. Sevoflurane has been postulated to prolong the QT interval as well as prolonging the action potential duration of accessory pathways – thus complicating mapping / ablation of these lesions [6].

Atrial Fibrillation (AFIB):

Ablation is now considered the standard of care for patients with AFIB resistant to medical therapy. Catheter ablation for AFIB attempts to create electrical isolation of the pulmonary veins either with Cryoablation or radiofrequency (RF) ablation and success depends on creating transmural lesions. While conscious sedation has been employed for years, recent studies have indicated improved success rates for patients undergoing ablation with general anesthesia[7]. Reduction in catheter motion is the postulated reason for improvements in results with GA due to less respiratory variation. Reducing catheter motion due to respiratory variation has become a hot topic and some centers have moved toward employing high frequency jet ventilation (HFJV) during the ablation period with some success.

Initially reported for AFIB ablation in 2006, HFJV has seen steady increase in use over the past 5 years at various centers. Goode et al reported results from a retrospective analysis comparing standard ventilation to HFJV in 72 patients (36 each group), and demonstrated reductions in number of required ablation lesions and reduced procedure time. Direct comparison demonstrated that HFJV produced less variation in LA volume, pressure, pulmonary vein blood flow velocity, and posterior LA position than standard ventilation [8]. Recently, Hutchinson and colleagues performed a randomized trial looking at use of integrated 3D EAM, steerable introducers, and HFJV. They reported improvements in one-year freedom from AFIB with the use of all three of these techniques, but improved even more with HFJV [9]. Elkassabany and colleagues reported retrospective results on anesthetic management of 188 patients for pulmonary vein isolation using HFJV[10]. 175 cases were completed using HFJV, while 13 cases were converted to standard ventilation due to either hypoxia or hypercarbia. These values were followed by ABG analysis. Reported airway complications in this study related to difficulty with intubation, and not

the HFJV itself. Not every anesthesiologist is comfortable using HFJV for an ablation procedure due to concern for barotrauma. Hu et al recently reported outcomes of >800 consecutive cases using HFJV for laryngeal surgery. Complication rates due to HFJV were reported in 5.8% of cases (57 events in 49 cases). Complications were hypoxia (SPO2 <90%, n = 30, 3.6%), hypercarbia (end tidal CO2 of >60 mm Hg, n = 17, 2.0%), airway obstruction (n = 4, 0.5%), barotrauma (n = 2, 0.2%), seeding of blood into trachea (n = 2, 0.2%), submucosal injection of air (n = 1, 0.1%), and mucosal damage (n = 1, 0.1%)[11]. Fernandez-Bustamante et al reported similar results in 2006 in HFJV use during rigid bronchoscopy with the complications being hypercapnia, hypoxemia, and hemodynamic instability, but just one case of barotrauma in the retrospective group[12].

The take home message for AFIB ablations at this time is that general anesthesia is preferred technique, although deep sedation may be appropriate in certain patients. HFJV can be considered, but use of HFJV probably is an indication for invasive arterial access to follow oxygenation and carbon dioxide levels.

Ventricular Tachycardia (VT):

Ablation procedures are seeing increasing success and use in VT. Patients who present for VT ablations generally fall into two categories: relatively healthy patients with symptomatic PVC's or idiopathic VT (no structural heart disease), or patients with structural heart disease (ischemic or non-ischemic cardiomyopathy). The second group tends to carry significant comorbid disease with various degrees of systolic or diastolic heart failure. Patients with idiopathic VT often undergo EAM / ablation initially with little sedation and often avoidance of local anesthetics to allow for spontaneous ventricular ectopy development and accurate mapping. Occasionally the arrhythmia requires induction either using vasoactive infusions (isoproterenol / epinephrine) vs electric stimulation, or burst pacing [4]. For ventricular arrhythmias that are hemodynamically stable, complete EAM may be carried out followed by ablation, and this is frequently accomplished for idiopathic VT.

Patients with structural heart disease (group 2) are much more challenging to manage from both the anesthesiologist and electrophysiologist standpoint. EAM in these patients is often done with minimal sedation as above, however triggering VT or sustained VT in patients with severe heart failure is often not tolerated and many times requires cardioversion / defibrillation. For this reason, invasive arterial line monitoring should be employed for patients with reduced EF having VT ablations. Due to the hemodynamic challenges of EAM in these cases, this period often requires vasopressor support and occasionally even ventricular assist device support of the LV (Impella) [5]. VT ablations in this category are now being approached both from the endocardial surface and epicardial surface. Obviously epicardial ablations require accessing the epicardial space, and add an additional level of complexity and risk, in addition to the need for additional anesthesia due to patient discomfort. A key aspect to success in VT ablations is direct communication with the EP team and anesthesiology team. Need for vasopressors can signal a change that can be due to procedural concerns or due to intrinsic heart problems, but this needs to be discussed immediately to rule our pericardial effusions or other procedure related complications (see below).

Complications of Ablations:

Vascular access complications are frequent but manageable and are well described by Price et al [5]. Pericardial effusions, tamponade, myocardial ischemia, and stroke are all procedure related complications that should be considered. Myocardial perforation occurs roughly 1% of the time and is monitored by fluoroscopy or ICE (intra-cardiac echocardiography). Onset of new unexplained hypotension should trigger concern for pericardial effusion / tamponade and should be immediately ruled out. Transient or permanent heart block can occur due to ablations, and occasionally temporary or permanent pacemakers need to be employed. Left sided ablations require anticoagulation to prevent stroke and thus ACT levels of 250-300 are often targeted. Phrenic nerve injury is also possible in various ablation approaches. Pacing and identifying the nerve during the procedure enables the electrophysiologist to monitor the phrenic nerve, thus use of neuromuscular blockade should be avoided. A rare complication during ablation procedures (0.04% in AFIB ablations) using RF is development of atrio-esophageal fistula due to heat injury, and thus esophageal temperature monitoring is often employed. Finally, fluid administration is employed during the ablation procedures to cool the probes, thus large amounts of fluid may be given over these lengthy procedures and is critical to monitor for patients with heart failure.

Hybrid OR / Catheterization Lab:

Lead Extractions:

Pacemaker insertion is now a well-established practice performed routinely in the US. The standard is for this to be done under sedation and local anesthesia, and patients generally do well. However with the large number of pacemakers and leads implanted annually, more leads become defective, fracture, or become infected requiring

removal. Lead removal can be accomplished via manual traction, specialized traction devices that clamp or snare the lead, mechanical sheaths that are advanced over existing leads and specialized sheaths. Specialized sheaths include: laser sheaths, electrosurgical sheaths, rotating tip sheaths, and telescoping sheaths. The Heart Rhythm Society has put out suggested guidelines for management of lead extractions from a system wide view (ie. not specific to anesthesiology) [13]. The following discussion will focus on the use of laser lead excision, but the concepts apply to all techniques.

The PLEXES (Pacing Lead Extraction With the Excimer Sheath) trial was the first large prospective, randomized report of laser extraction techniques. This trial, which included 301 patients, showed 94% success using laser extraction vs 64% success using non-laser extraction techniques [14]. Subsequently, Byrd et al. reported 2,561 laser-assisted pacing and defibrillator lead extractions from 1,684 patients at 89 sites with a procedural success rate of 90% and a major complication rate of 1.9% [15]. Interestingly, this complication rate was similar to a previously reported non-laser technique major complication rate of 1.96% [14]. Hence, even with excimer laser lead extraction catastrophic complications remain possible, with mortality rates as high as 50% in the event of accidental rupture of a large vein or of the heart itself [16].

The removal of chronically implanted leads is impeded by dense fibrotic attachments that entrap the leads within the veins and cardiac chambers [16]. Reports of major complications from laser extraction of chronically implanted leads range from **1.9% to 3.4%** [15,17-19]. **Major complications include major venous injury, myocardial tear, arrhythmia, arteriovenous fistula, pneumothorax, hemothorax, tricuspid valve injury, and pulmonary embolus [20,21].** Because of the potential need for immediate surgical intervention including the institution of cardiopulmonary bypass, many institutions now elect to adhere to the Heart Rhythm Society recommendations which is to perform these procedures with immediate access to open-chest -surgery including cardiopulmonary bypass [13].

Based on the experience at University of Colorado Denver (UCD), a protocol using general anesthesia under the direction a cardiothoracic anesthesiologist has been adopted. Arterial catheters are placed in all patients to permit rapid evaluation of hemodynamic stability. It is not necessary to monitor central venous or pulmonary arterial pressures in all patients. The procedure itself involves central venous cannulation for emergency temporary transvenous pacing access, so this access can also be used for either monitoring or for infusion of vasoactive drugs. For patients with significant pulmonary hypertension (mean pulmonary artery pressure >30mmHg) it may be beneficial to have a pulmonary artery (PA) catheter in place, though this may not be needed given availability of TEE monitoring. At UCD, a protocol is used for TEE monitoring for lead extractions. All patients receive a standard comprehensive TEE examination under general anesthesia immediately prior to the lead extraction procedure as described in ASE/SCA guidelines [22]. Special attention is given to assessing for the presence of a patent foramen ovale (PFO) before use of the laser, since the laser generates gas bubbles that may embolize into the systemic circulation in the presence of a right-to-left shunt. Efforts are also made to identify thick fibrinous sheaths on leads, infective endocarditis with vegetations, and lead thrombi, all of which may embolize during extraction and increase the chance for ischemic stroke. Commonly, the first obstruction point is at the junction of the superior vena cava (SVC) and right atrium (RA). Trauma to the SVC at this location may predispose to laceration or tearing and lead to either right-sided hemothorax or pericardial effusion, depending upon the specific location of the tear. The presence of a high (cephalad) SVC laceration is not usually detectable with TEE; therefore a strong index of suspicion as well as surveillance of the right pleural space should be undertaken.

Leads commonly adhere to the tricuspid valvular apparatus and extraction of fibrosed leads can further damage TV leaflets. The TV is best seen in the ME 4-chamber and ME RV inflow-outflow views. All 3 leaflets can also be seen in the transgastric window, commonly found between 20° to 50° (TV SAX view). RV leads are usually implanted along the RV septum in order to minimize the chances of the lead causing RV free wall damage. Extraction of RV leads at their distal insertion point should also be closely monitored. Traction on the RV can cause significant hemodynamic compromise as a result of RV distortion or inversion. If observed, it should be communicated to avoid potential papillary muscle injury or ventricular rupture.

Perforation of the either the atrial or the ventricular wall can occur during extraction procedures and the presence of new or growing pericardial effusion should be vigilantly monitored during the procedure. The ME 4-chamber view or the transgastric left ventricle SAX view are ideal views for diagnosing and monitoring this complication. The presence of trivial to small pericardial effusions is common and seen in up to 14.5% of cases [23], the majority of which can be managed conservatively and monitored with post-operative transthoracic echocardiography; however clinically / hemodynamically significant effusions may require immediate pericardiocentesis or even sternotomy and direct surgical repair with or without cardiopulmonary bypass. Finally, these procedures typically will finish with placement of new pacemaker leads, either temporary in cases of infection,

or permanent. Guidance of placement of these leads is done using fluoroscopy and TEE imaging. TEE images are useful to confirm that the leads are placed in the appropriate location, ie on the RV septum and not the RV free wall.

Lariat Procedure:

A new approach to management of AFIB has recently come to clinical practice, the so-called Lariat Snare device [24-26]. AFIB affects > 2 million patients currently, and is expected to increase up to 12 million by 2050[24]. While anticoagulation therapy is effective in reducing stroke risk for many patients, a certain subset are unable to be adequately maintained on this due to excessive bleeding risk. Interventional exclusion of the left atrial appendage has been developed using a snare device. The procedure is done under general anesthesia with TEE guidance throughout along with fluoroscopy. Two access points are needed: **L. atrium** via femoral venous sheath / transeptal puncture from the R. atrium to L. Atrium, and the **pericardial space** approached through the chest wall. The procedure involves 4 basic steps: 1) pericardial and transseptal access; 2) placement of the endocardial magnet-tipped guidewire in the apex of the LAA with balloon identification of the LAA os; 3) connection of the epicardial and endocardial magnet-tipped guidewires for stabilization of the LAA; and 4) snare capture of the LAA with closure confirmation and release of the pre-tied suture for LAA ligation[26]. The main procedural risks include: including right ventricular puncture, epicardial vessel injury, sheath-related trauma, and post-procedure pericarditis, laceration of the LAA, trauma to the epicardial surface of the myocardium, and incomplete closure due to the inability to reposition the snare[26].

As expected in any new interventional procedure, there is a learning curve for the interventionalist, as well as for the team management of these cases. While this procedure does not fall under the same recommendations as lead extractions, due to the risks outlined above, availability of CT surgery teams, cardiac anesthesia, and perfusion teams / equipment should be readily available should significant injury to cardiac structures occur requiring open surgery. Due to these risks, the anesthesia team should consider invasive blood pressure monitoring along with the TEE monitoring.

Percutaneous Mitral Valve Repair:

Dr. Alfieri introduced the edge-to-edge repair for mitral lesions in 1991 as a simplified solution to open surgical MV repair techniques[27]. Various companies have developed percutaneous techniques for mitral repair based on this concept. The FDA approved the Mitra-clip by Abbot in the US for use as of 2013, largely based on results of the EVEREST II trial (Endovascular Valve Edge-to-Edge Repair) High Risk Study (HRS)[28], which looked at high surgical risk patients (>12% estimated mortality) with grade III/IV MR. Device repair was achieved in in 96% of the 76 patients. Outcomes at 12 months were compared to the control group identified with similar risk and severity of MR, but deemed not to be appropriate candidates. Standard management was employed for the control group – with 86% managed medically and 14% managed with open surgical repair. 12-month survival rate was 76% for intervention group and 55% for control group. The intervention group also demonstrated reduction in MR severity. LV volume, improvement in NYHA classification, and improved quality of life indicators [28].

Percutaneous MV clipping is performed in the hybrid suite or catheterization lab under a combination of TEE and fluoroscopy guidance. Anesthetic planning should include consideration of heart failure due to severe MR and appropriate induction agents should be employed. Invasive arterial access should be considered, as there can be hemodynamic changes during device placement. General anesthesia is typically utilized due to prolonged procedure times and need for TEE guidance. Trans-septal puncture is initially carried out to access the left atrium, followed by identification of the appropriate MV segments by imaging. The device is placed and once secured, follow up imaging confirms appropriate placement. Overall risks of the procedure include vascular access concerns, residual septal defect, stroke, and potential embolization of the device.

Percutaneous Septal Defect Repair:

Atrial septal defects account for roughly 10% of congenital heart disease in adults, and if left untreated can result in RV overload, increased RV volumes, pulmonary hypertension, elevated risk of embolism, and atrial arrhythmias[29]. Initial attempts at device closure of septal defects dates back to 1974, with multiple versions and attempts made at device employment. In 199,1 the Amplatzer device was released; a nickel and titanium self-expanding device that is used in many cases currently. Data from the Nationwide Inpatient Sample identified 15,482 secundum ASD/patent foramen ovale closures between 1988 and 2005. Roughly 1/3 of these were managed with percutaneous therapy. Currently, both the Amplatzer septal occluder (ASO), and the Helex septal occluder (HSO) are FDA approved for use in the US[29].

ASO devices are indicated for closure of secundum ASD with Qp:Qs ratio of 1.5 : 1, or fenestration

following Fontan repair. Available sizes are from 3mm -38mm. Reported complications include: device embolization, erosion into adjacent cardiac structures, arrhythmias, fracture of device, stroke, and device thrombus. The procedure itself includes access of the femoral vein, and access to the right atrium with the guidewire. Balloon sizing of the ASD is done under TEE / fluoroscopy guidance, with specific attention paid to the amount of ASD rim tissue. Anesthetic management is typically to use GA. Planning with the cardiology team prior to the procedure is important, specifically regarding need to measure Qp:Qs ratios. The cardiology team may want to obtain access and measure RA and PA pressures under spontaneous respiration on room air prior to induction of anesthesia. In this case, GA is typically induced following these measurements. Hemodynamic changes are relatively minor in this procedure, so in the absence of significant heart failure symptoms, invasive arterial monitoring is often not employed.

Table 1: Summary of key anesthesia management points:

Intervention / Procedure:	Anesthetic Management Points*:
AFIB Ablation	General Anesthesia preferred Consider HFJV (+ Arterial line if HFJV) Esophageal Temp monitoring Typically stable hemodynamics throughout Avoid Neuromuscular blockade during ablation
SVT Ablation	Sedation preferred over General Anesthesia Invasive Arterial monitor not indicated Typically stable hemodynamics throughout Avoid Neuromuscular blockade during ablation
VT Ablation	EAM initially done without sedation and minimal local anesthesia General Anesthesia / deep sedation once mapping completed + Arterial line due to risk of hemodynamically unstable VT Patients with EF < 30% may not tolerate arrhythmia induction / ablation Plan for Inotropic support and consider mechanical support in extreme cases (ie Impella Ventricular Support device) Avoid Neuromuscular blockade during ablation
Lead Extraction / Laser Lead	General Anesthesia – but possible with local / sedation Arterial line + TEE monitoring. Adequate IV access required, consider central access Type and Crossmatch with products immediately available CT surgery / Perfusion standby Cardiac Anesthesiologist**
Lariat	General Anesthesia Arterial line + TEE monitoring. Adequate IV access required, consider central access Type and Crossmatch with products immediately available CT surgery / perfusion standby Cardiac Anesthesiologist**
Percutaneous MV repair	General Anesthesia TEE guidance + Arterial line Cardiac Anesthesiologist**
Percutaneous ASD closure	May start with local / spontaneous ventilation on Room Air General Anesthesia once Qp:Qs measurements taken TEE guidance Cardiac Anesthesiologist**

*All cases should have standard ASA monitoring in place. Specific anesthesia planning should be based on individual medical conditions and may be altered from recommendations in table 1.
**Current debate surrounding whether CT Anesthesiologists should staff these cases, and may depend on whether cardiology vs anesthesiology is performing TEE.

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