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Non-Operating Room Anesthesia

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Introduction

Due to advances in technology in electrophysiology (EP), interventional cardiology, and transesophageal echocardiography (TEE) technology, complex interventional procedures that may require anesthesia care are usually performed in these specialized settings remote from the main operating rooms. Many patients requiring such procedures have severe cardiovascular disease or pulmonary comorbidity; thus, they are at high risk for oversedation and hemodynamic instability. Even relatively healthy patients may not tolerate remaining motionless during prolonged or painful interventional procedures. For these reasons, the number of cases that require monitored anesthesia care (MAC) or general anesthesia in these off-site settings has increased.

Anesthetic Challenges in Off-site Locations

Typically, EP, interventional cardiology, and TEE suites are remote from the main operating room (OR) area. Challenges for anesthesiologists in such off-site locations often include lack of standard anesthesia machines, monitors, supplies, or scavenging equipment for anesthetic gases. Additional time is required for transport of necessary items from a distant OR location, and subsequent setup and positioning of all equipment in the off-site location. Ensuring availability of well-located portable shields, lead aprons, thyroid collars, and eye protection for all anesthesia personnel is necessary for procedures with radiation risks. Another challenge is interdisciplinary communication, which may be hindered by lack of familiarity with the procedures and techniques planned by each specialist.

Patient and Procedure-related Considerations I

- Cardiovascular pathology for which the procedure is being performed influences anesthetic management. In particular, arrhythmias, acute coronary syndrome, cardiomyopathy, valvular heart disease, or presence of a cardiac implantable electronic device may affect anesthetic care and risk of complications.
- Comorbid conditions (eg, obstructive sleep apnea [OSA], morbid obesity, chronic obstructive pulmonary disease [COPD], pulmonary hypertension with right heart dysfunction) may cause respiratory or hemodynamic compromise during sedation or general anesthesia.

Patient and Procedure-related Considerations II

- Patients with preexisting renal insufficiency are at increased risk for developing acute kidney injury, particularly if intravenous (IV) contrast media is used during the procedure.
- Risks for an allergic reaction are assessed, including history of prior allergic reaction to iodinated contrast agents or to protamine . Preoperative steps to reduce or mitigate severity of allergic reactions include premedication with corticosteroids and H1 antihistamines , as well as use of a nonionic contrast agent if feasible.

Management of Preoperative Medications

For procedures in the interventional cardiology or TEE suites, doses of chronically administered cardiovascular medications (eg, beta blockers, statins, aspirin) are typically administered at their usual times before an interventional procedure. Timing of the most recent doses of anticoagulant or antiplatelet medications is particularly important, since these agents increase risk for bleeding during EP and interventional procedures. However, many patients undergoing EP procedures require ongoing anticoagulation to prevent periprocedural thrombus formation, similar to patients undergoing cardioversion of AF.

Antiarrhythmic medications that affect atrioventricular (AV) node conduction (eg, calcium channel blockers, digoxin) are typically discontinued several days prior to a scheduled invasive EP procedure; however, beta blockers may be gradually tapered.

Premedication Prophylaxis

Premedication prophylaxis for patients with previous acute reaction to iodinated contrast

Nonurgent oral premedication:
Glucocorticoid-preferred regimen:
Adult: Oral prednisone 50 mg at 13, 7, and 1 hour prior to contrast administration.
Pediatric: Oral prednisone 0.5 to 0.7 mg/kg (maximum 50 mg per dose) at 13, 7, and 1 hour prior to contrast administration.
Glucocorticoid-alternate:
Adult: Oral methylprednisolone 32 mg at 12 and 2 hours prior to contrast administration.
Pediatric: Oral methylprednisolone 1 mg/kg (maximum 32 mg per dose) at 12 and 2 hours prior to contrast administration.
AND
H1 antihistamine:
Adult: Diphenhydramine 50 mg oral, IM, or IV 1 hour prior to contrast administration.
Pediatric: Diphenhydramine 1.25 mg/kg oral, IM, or IV (maximum 50 mg) 1 hour prior to contrast administration.
Urgent intravenous premedication (eg, inpatients, emergency department):*
Hydrocortisone 200 mg IV 5 hours and 1 hour prior to contrast administration and 50 mg IV diphenhydramine 1 hour prior to contrast administration.

Selection of Anesthetic Technique I

For interventional procedures in the EP, interventional cardiology, or TEE suite that are not likely to have a prolonged duration or result in hemodynamic instability, minimal or moderate sedation is typically performed by credentialed nursing staff and interventional cardiologists, without the presence of an anesthesiologist.

American Society of Anesthesiologists (ASA) Definitions of Levels of Sedation/Anesthesia

1. Minimal sedation (anxiolysis)
a. Drug-induced sedation
b. Patient responds normally to verbal commands
c. Cognitive and motor function may be impaired
d. Ventilatory and cardiovascular functions maintained normally
2. Moderate sedation/analgesia (conscious sedation)
a. Drug-induced sedation
b. Patient responds purposefully to verbal commands either alone or with light tactile stimulation
c. Patient maintains a patent airway and spontaneous ventilation
d. Cardiovascular function maintained
3. Deep sedation/analgesia
a. Drug-induced sedation
b. Patient cannot be easily aroused but can respond purposefully to repeated or painful stimulation
c. Ventilatory function may be impaired, requiring assistance in maintaining a patent airway, and spontaneous ventilation may be inadequate
d. Cardiovascular function is usually maintained
4. General anesthesia
a. Drug-induced loss of consciousness
b. Patients are not aroused by painful stimulation
c. Ventilatory function is often impaired; patient may require assistance in maintaining a patent airway
d. Spontaneous ventilation may be impaired, as well as neuromuscular functioning
e. Positive pressure ventilation is often required
f. Cardiovascular function may be impaired

Selection of Anesthetic Technique II

The interventional team may consult anesthesia personnel to determine what type of anesthetic care is necessary when minimal or moderate sedation is not appropriate. For example, deep sedation with monitored anesthesia care (MAC) may be selected in patients with severe anxiety, inability to lie supine, morbid obesity, a difficult airway, or significant cardiovascular disease or comorbidities.

Electrophysiology Procedures

Several sedative and/or opioid agents may be employed by anesthesia personnel to provide moderate or deep sedation as needed. Typically, a propofol infusion is titrated at 25 to 75 mcg/kg per minute, with or without an initial propofol bolus. An opioid may be added, typically remifentanil 0.025 to 0.1 mcg/kg per minute. Another common option is dexmedetomidine, which produces sedation with minimal respiratory changes . Alternative regimens include combinations of other sedative and analgesic agents (eg, ketamine, midazolam, or other opioids, such as fentanyl)

General Anesthesia with Conventional Ventilation I

If general anesthesia is requested, adequate intravenous (IV) access is critical since the patient's arms are typically tucked at the sides and inaccessible during the procedure. In most cases, a second peripheral IV catheter is inserted before or shortly after induction of general anesthesia so that multiple drugs or infusions can be administered.

An intra-arterial catheter is inserted in selected patients with high cardiovascular risk (eg, very low ejection fraction, arrhythmias with a ventricular response too rapid for accurate monitoring with a blood pressure cuff, hemodynamic instability) or when multiple blood samples are required to monitor anticoagulation or arterial blood gases.

A neuromuscular blocking agent (NMBA) may be administered to facilitate endotracheal intubation, but long-acting agents are avoided if phrenic nerve stimulation is planned (eg, during cryoablation)

General Anesthesia with Conventional Ventilation II

An esophageal temperature probe is inserted orally. Insertion of the temperature probe via the nasal route is avoided, particularly if the patient received a recent dose of an anticoagulant agent, due to the possibility of significant nasal bleeding.
In selected patients, transesophageal echocardiography (TEE) examination may be performed before beginning the EP procedure, with particular attention to the left atrial (LA) appendage, in order to ensure absence of intracardiac thrombus and thereby reduce stroke risk. If intracardiac thrombus is detected, the procedure is cancelled and rescheduled. For this reason, if suspicion for thrombus is high, TEE may be performed the day before the procedure or prior to induction of general anesthesia. If a TEE examination is to be performed immediately after induction, short-acting anesthetics and NMBAs are selected, so that rapid awakening can be achieved if thrombus is detected.

General Anesthesia with Conventional Ventilation III

General anesthesia may be maintained with a technique that employs either inhalation or IV anesthetics as the primary agents, or a combination of agents administered by both routes. Although many anesthetics cause mild prolongation of the QT interval ($>$440 ms) or slight depression of sinoatrial (SA) or atrioventricular (AV) nodal function (eg, volatile anesthetic agents, opioids, dexmedetomidine, midazolam, etomidate, ketamine), these effects are not clinically significant and do not preclude their use . In general, there are no anesthetic agents that are specifically avoided. If an opioid is administered, a short-acting agent is preferred.

Ventilation

When patients are receiving standard positive pressure mechanical ventilation, frequent temporary pauses in respiration (eg, 10 to 60 seconds) may be necessary during critical periods of certain procedures to facilitate stability of an ablation catheter.

General Anesthesia with Jet Ventilation I

The use of high frequency jet ventilation (HFJV) is requested by some electrophysiologists during critical periods of ablation procedures to decrease chest wall excursions and facilitate stability of the ablation catheter.
A second reliable peripheral IV is inserted for administration of agents for a total IV anesthesia (TIVA) technique.
Neuromonitoring with a processed or unprocessed electroencephalogram (EEG) such as the bispectral index (BIS) or patient state index (PSI) is typically employed to minimize risk of awareness during TIVA.

General Anesthesia with Jet Ventilation II

An intra-arterial catheter is often inserted before or after anesthetic induction to monitor arterial blood gases (ABGs) before, during, and after the period of jet ventilation, particularly in patients with severe cardiopulmonary disease (eg, heart failure, severe pulmonary disease). In patients without significant comorbidities, venous blood gases may be obtained by the electrophysiologist from the femoral venous access catheter to assure adequacy of ventilation rather than inserting an intra-arterial catheter to obtain ABGs.

General Anesthesia with Jet Ventilation III

TIVA is necessary during jet ventilation because the anesthesia machine is temporarily removed from the breathing circuit so that use of an inhalation agent is precluded.
Agents employed for the TIVA technique include a propofol infusion at 100 to 150 mcg/kg per minute combined with an opioid. A remifentanil infusion at 0.1 to 0.2 mcg/kg per minute is typically selected.
Just before HFJV is required, general anesthetic depth is increased because initiation of this ventilatory technique stimulates airway reflexes and may cause coughing or bucking. Administration of a bolus dose of an opioid (eg, remifentanil 50 to 100 mcg) attenuates the sympathetic response to this stimulation.

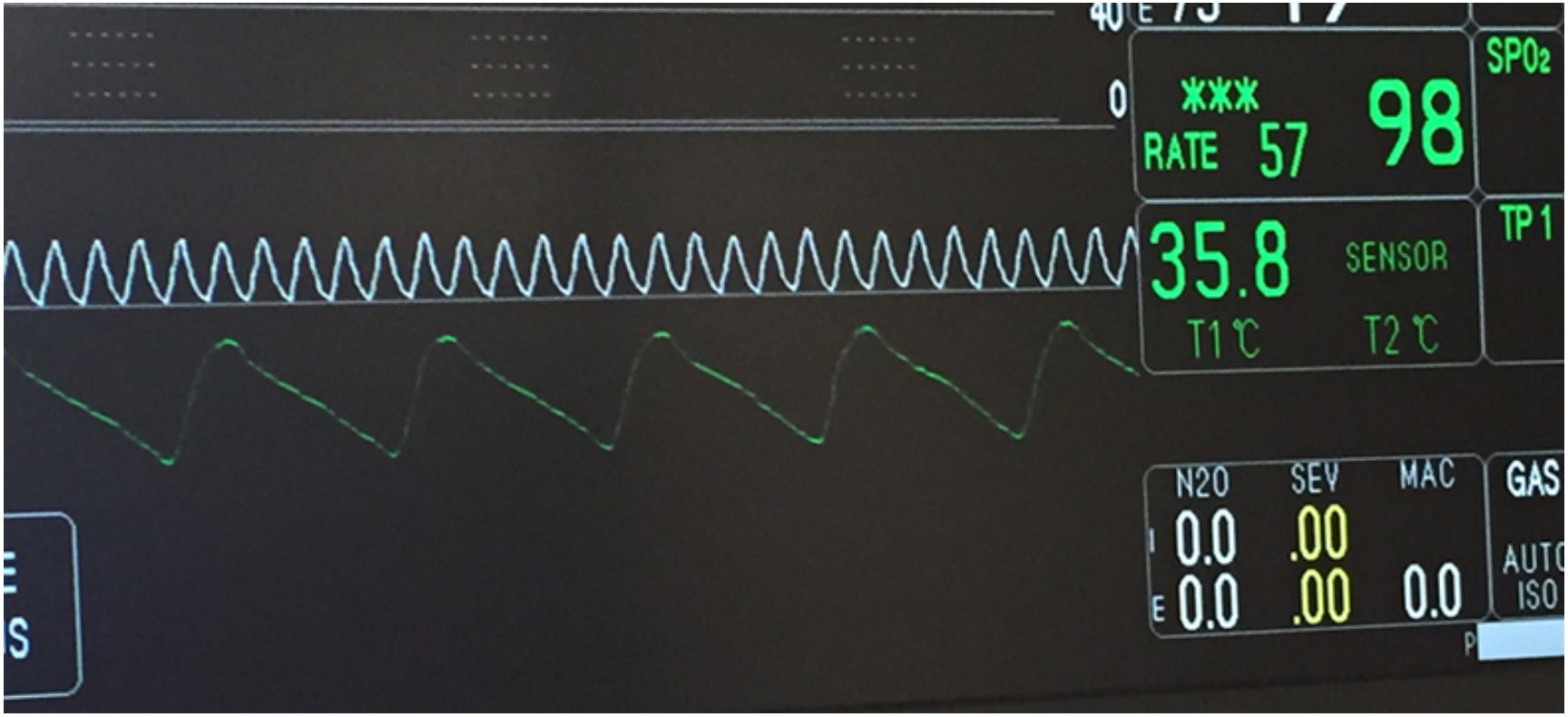
Jet Ventilation I

- Driving pressure – 30 pounds/square inch (psi)
- Frequency of respirations – 100 breaths/minute
- Fraction of inspired oxygen (FiO_2) – 80 percent
- Inspiratory fraction – 30 percent
- Humidity – 50 percent

Jet Ventilation II

End-tidal carbon dioxide ($ETCO_2$) monitoring is employed throughout the period of HFJV. A "saw-tooth" appearance of the $ETCO_2$ waveform is typical .

Typical $ETCO_2$ Tracing During High Frequency Jet Ventilation



Jet Ventilation III

Arterial blood gases are monitored before and shortly after initiating HFJV, approximately every 30 minutes during HFJV, and once more shortly after reestablishing conventional ventilation.

Jet Ventilation IV

If hypercarbia develops, setting changes to correct the problem include:

- Decreasing the frequency of respirations (eg, to 80 bpm), thereby allowing more time in the expiratory phase for passive diffusion of CO_2
- Decreasing the inspiratory time (eg, to 25 percent), thereby increasing the expiratory phase
- Increasing the driving pressure (eg, to 32 psi)

Jet Ventilation V

The decision to use HFJV is carefully considered in each individual patient and reevaluated as the EP procedure proceeds.
Hypercarbia and/or increased plateau pressure with barotrauma risk may occur due to factors such as COPD, asthma, or morbid obesity. If these problems cannot be corrected by changing HFJV settings, its use is abandoned and controlled mechanical ventilation is resumed at appropriate settings.
Anticoagulation with heparin is common during EP procedures .
Protocols for heparin administration depend on the specific procedure and institutional and/or electrophysiologist preferences.
Typically, monitoring of activated whole blood clotting time (ACT) is employed to achieve a targeted value indicating adequate heparin effect during the procedure, as well as adequate reversal with protamine at the end of the procedure.

Jet Ventilation VI

Protamine is typically administered prior to intravascular sheath removal. The trachea may be extubated before or after the femoral sheaths are removed at the end of the procedure. Since coughing after sheath removal may result in significant bleeding and hematoma at the intravascular cannulation site

Atrial Fibrillation Ablation

Atrial fibrillation (AF) ablation may be performed using circumferential point-by-point radiofrequency ablation (RFA) lesions or using the cryoballoon ablation (CBA) technique to electrically isolate the pulmonary vein ostia from the body of the LA, thereby eliminating the trigger(s) for AF. General anesthesia is typically necessary, and some electrophysiologists use HFJV during critical portions of the procedure.

Radiofrequency Ablation (RFA) I

RF energy heats myocardial tissue and can cause thermal injury to adjacent structures such as the esophagus. The electrophysiologist uses radiographic imaging to identify the esophageal temperature probe and assist the anesthesiologist in positioning it in the esophagus directly behind the myocardial foci targeted for ablation. During active ablation, the anesthesiologist and electrophysiologist continuously monitor esophageal temperature to avoid burn injury.

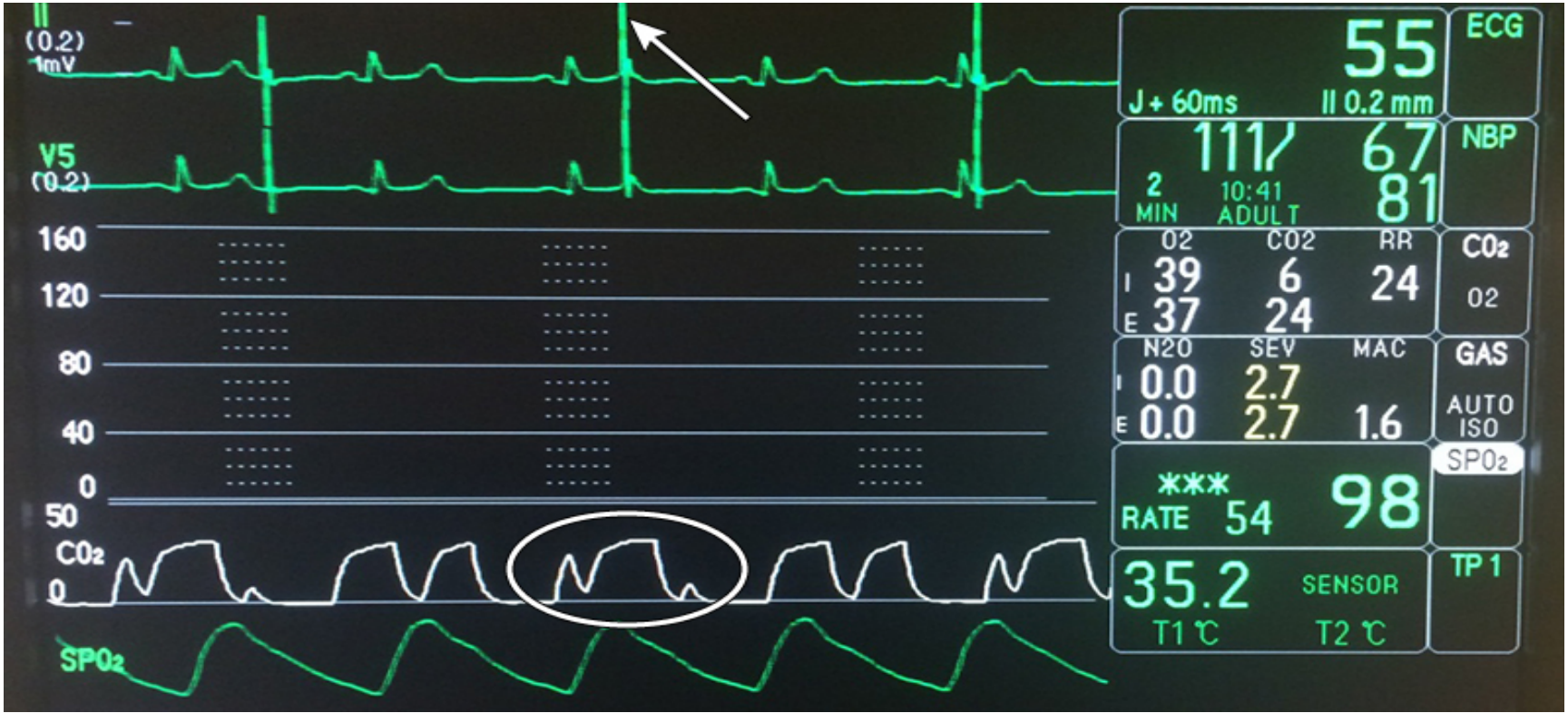
Radiofrequency Ablation (RFA) II

Saline flushing via the ablation catheter is employed by the electrophysiologist to cool the myocardium throughout an RFA procedure. Since several liters of fluid may be administered by such flushing, the anesthesiologist needs to minimize IV fluid administration and calculate total fluid balance at frequent intervals (eg, every 30 minutes). If fluid overload is suspected, an intraoperative dose of furosemide 20 mg IV may be administered to achieve diuresis.

Cryoballoon Ablation (CBA)

Cryothermal energy freezes myocardial tissue by insertion of a balloon-based catheter into each individual pulmonary vein; this catheter can expand and freeze the surrounding tissue. Phrenic nerve stimulation is used if cryoablation sites are near this nerve , necessitating avoidance of neuromuscular blockade.

$ETCO_2$ Waveform Demonstrating Effects of Phrenic Nerve Pacing



Ventricular Arrhythmias I

Endocardial ablation

Most VT ablations are performed via endocardial ablation. This is always the case in patients with previous heart surgery or thoracic radiation because the pericardial space has been obliterated and the epicardium is inaccessible. The left ventricular (LV) endocardium can be accessed in a retrograde manner with a catheter inserted through the femoral artery into the aorta and across the aortic valve, or anterograde through the femoral vein with transseptal placement into the LA, across the mitral valve, and into the LV.

Ventricular Arrhythmias II

Deep sedation with MAC is typically employed for endocardial ablation of recurrent slow VT or frequent premature ventricular contractions (PVCs) in patients who are hemodynamically stable. In patients with actual or potential hemodynamic instability, general anesthesia is employed.

Epicardial Ablation I

Epicardial subxiphoid percutaneous puncture for pericardial access may be employed if the patient's arrhythmia arises from the epicardial surface of the heart. Epicardial ventricular mapping can also be performed with recording catheters that are steered in the branches of the coronary sinus.

Epicardial Ablation II

Epicardial ablation is performed under general anesthesia because pericardial access and catheter manipulation can be painful. Patients with frequent episodes of malignant arrhythmias, acute coronary syndrome, or severe heart failure may develop hemodynamic instability during a VT ablation procedure. In such cases, an intra-arterial catheter is inserted prior to or following induction of general anesthesia for continuous monitoring of systemic blood pressure.

Implantation of CIED and Lead Systems I

Transvenous implantation of CIED lead systems and the accompanying subcutaneous implantation of the pulse generator for the device (eg, implantable cardioverter-defibrillator [ICD] or PM) are procedures typically performed with moderate sedation.

Implantation of CIED and Lead Systems II

Regardless of anesthetic technique, transcutaneous pacing/defibrillator pads are placed on the patient before beginning the procedure, and an external defibrillator with pacing capability should be immediately available .
Testing of an ICD by inducing ventricular fibrillation (VF) is occasionally performed after lead or device implantation to confirm that the newly implanted ICD can successfully terminate the arrhythmia. In the event of device failure, immediate defibrillation is accomplished via the transcutaneous defibrillator pads that were previously placed on the patient.

Cardioversion

The anesthetic goal for cardioversion is to provide deep sedation with loss of consciousness, which should last for only the few seconds required for one or two cardioversion attempts, while avoiding apnea and the need for assisted ventilation.
Typically, small bolus doses of propofol (eg, 10 to 50 mg increments) are titrated to produce loss of response to verbal commands and loss of eyelash reflex. Small bolus doses of midazolam (eg, 1 to 2 mg) may be added. Prolonged apnea is avoided.

Transesophageal Echocardiography Procedures I

Considerations for patients with COVID-19 — Since transesophageal echocardiography (TEE) examination is an aerosol-generating procedure, it should be avoided in patients with known or suspected novel coronavirus disease 2019 (COVID-19) unless the findings are likely to be critically important . Thus, elective TEEs are postponed and alternative imaging modalities are used in some urgent cases. For example, a cardiac computed tomography (CT) can be used to exclude a left atrial appendage thrombus prior to cardioversion for atrial fibrillation (AF). Important anesthetic considerations specific to patients with suspected or confirmed COVID-19 who do undergo endoscopy include the following:

Transesophageal Echocardiography Procedures II

- Whenever possible, TEE should be performed in a negative-pressure procedure room.
- During TEE examination, airborne, contact, and droplet personal protective equipment (PPE) should be worn to prevent infection, which consists of an N95 or higher level respirator or powered air purifying respirator, eye protection (eg, goggles or face shield that goes around the side of the face), gloves, disposable gown, operating room cap, and shoe covers.

Transesophageal Echocardiography Procedures III

- Whenever possible, general anesthesia with endotracheal intubation rather than sedation with monitored anesthesia care (MAC) is employed.
- Some centers employ a sheath for the TEE probe to further reduce the risk of provider and environmental contamination , and/or cover the ultrasound system (controls) with a plastic barrier. Additional precautions include minimizing the number of personnel performing TEE examination, limiting TEE use by performing a focused examination, and using dedicated TEE equipment for COVID-19-positive patients.

Transesophageal Echocardiography Procedures IV

In most patients, TEE examination is performed with local anesthesia applied to the posterior oropharynx and moderate sedation.
The anesthetic goal is for the patient to maintain spontaneous respiration throughout the procedure, without need for additional airway support other than nasal cannulae for oxygen administration.
Insertion of the TEE probe is the most stimulating portion of the procedure because probe placement elicits upper airway and gag reflexes. These reflexes can be attenuated by topical oropharyngeal administration of lidocaine, typically 200 to 400 mg of a 4% solution sprayed into the mouth.

Percutaneous Aortic Valve Replacement (Transcatheter Aortic Valve Replacement)

Percutaneous aortic valve replacement or transcatheter aortic valve replacement (TAVR) is a relatively new treatment in the U.S. for aortic stenosis. During the procedure, a replacement valve is crimped into a catheter and passed through the femoral artery to the aortic annulus. Rapid ventricular pacing is employed to minimize cardiac output while the prosthesis is deployed into the appropriate position after a balloon valvuloplasty.

Critical Procedural Steps During Transfemoral Transcatheter Valve Replacement I

- Place intravenous line and arterial line, induction.
- Place PA line, larger access, cerebral Svo_2.
- Conduct TEE, discussion of expected and unexpected findings with entire team.
- Access femoral vasculature: arterial sheath, contralateral transfemoral aortic occlusion balloon, and place transvenous pacer.
- Perform standard balloon aortic valvuloplasty: refine sizing and enlarge orifice.

Critical Procedural Steps During Transfemoral Transcatheter Valve Replacement II

- Assess adequacy of rapid ventricular pacing.
- Upsize sheath to (27 Fr) or appropriate introducer.
- Advance transcatheter valve; assess position by fluoroscopy and echocardiography.
- Deploy valve during rapid ventricular pacing.
- Assess valve position and function.
- Remove sheath and complete vascular closure.

Critical Procedural Steps During Transfemoral Transcatheter Valve Replacement III

Large peripheral intravenous lines should be placed for volume administration. Invasive arterial pressure monitoring is important because noninvasive blood pressure cuffs may not work when the patient is rapidly paced. Central access is useful for infusions and a Swan-Ganz catheter is recommended in compromised patients. TEE plays a critical role in the management of patients undergoing TAVR . Before any intervention, aortic stenosis with a trileaflet valve should be confirmed—TAVR cannot be performed with bicuspid valves.

Critical Procedural Steps During Transfemoral Transcatheter Valve Replacement IV

The degree of aortic insufficiency should be assessed before valvuloplasty, as the presence of preoperative mild to moderate aortic insufficiency may be protective in severe new-onset cases after balloon aortic valvuloplasty. Ejection fraction, degree of mitral and tricuspid regurgitation, presence of mitral annular calcification and mitral stenosis, estimated pulmonary artery pressures, and coronary artery takeoff location are also useful measurements. Accurate measurement of the aortic annulus aids in the choice of prosthetic valve size. During the placement of the valve, real-time echocardiographic guidance, either 2D or 3D, can assess positioning of

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