Update on Cardiac Anesthesia

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Like most medical subspecialties, cardiac anesthesia continues to move at a rapid pace. The topics chosen for this year’s update affect the day-to-day life of the cardiothoracic anesthesiology subspecialist most often, but they increasingly affect the clinical practice of anesthesiology outside the cardiac surgical operating suites as well. These topics are ventricular assist devices, percutaneous Mitraclip placement for mitral regurgitation, and transcatheter aortic valve replacement.

Ventricular Assist Devices.

Over 500,000 new cases of congestive heart failure (CHF) present each year in the United States, and over 5 million patients are undergoing treatment for CHF. Only a subset of CHF patients can or should receive one of the limited number of cardiac transplants available each year (approximately 2,500), but continuing improvement in outcomes for ventricular assist devices (VAD) patients is increasing the appeal of that option. For the purpose of this lecture, principally destination-type left ventricular assist devices (LVADs) will be discussed. The term “destination” refers to using a VAD as the intended permanent treatment for advanced heart failure, as opposed to using it as a “bridge” to transplantation or recovery. Although most VAD therapy is still considered experimental by the FDA, a trial known as REMATCH (Randomized Evaluation of Mechanical Assistance in the Treatment of Congestive Heart failure) showed survival benefit and improvement in the quality of life when VAD therapy was compared to medical management (Sun 2008). Although medical management of CHF has improved markedly over the past decade, the prospects for long-term survival appear less promising than do those for mechanical support. In 2006 Parides (2006) noted that the potential exists for implantation of 20,000-60,000 VADs per year as destination therapy for CHF, yet fewer than 500 implantations were then being performed annually in the US. He attributed this to a variety of causes including a cumbersome FDA approval process and refusal by some health insurance plans to reimburse for this procedure. The concurrent presence of several experimental VADs has impaired acquisition of sufficient numbers of patient implantations and long-term outcome measurements for any single device to attain standard-of-care status, but this limitation is diminishing as the Heartmate II nonpulsatile pump takes center stage. Since 2006 the annual number of LVAD implants has risen to a total approximating 1,000 in 2009, but this still falls far short of the projected need (INTERMACS).

Most LVADs provide assistance by taking inflow from the apex of the left ventricle and delivering outflow into the ascending aorta. The greatest experience accumulated to date has been with the Thoratec Heartmate (Thoratec, Inc., Pleasanton, CA) series of pumps, which provide pulsatile assistance via a device implanted into a pocket in the anterior abdominal wall; the device contains inflow (“mitral”) and outflow (“aortic”) valves. Biocompatibility of the
blood contact surfaces is sufficiently favorable that patients can usually be managed long-term with just aspirin antithrombosis prophylaxis. The device is a bit bulky and requires an external power source, but the external hardware required is equivalent to that of many pulmonary patients who require round-the-clock oxygen supplementation. Axial flow pumps (e.g., Heartmate II, Thoratec, Inc., Pleasanton, CA; Jarvik 2000 (Cardiowest), Syncardia, Tucson, AZ; DeBakey VAD, Micromed Cardiovascular, Inc. Houston, TX) provide sufficient flows with less bulk by using a continuous flow mechanism that requires no valves (Sun 2008). This nonpulsatile mechanism is efficient but complicates and sometimes precludes noninvasive assessment of blood pressure and SPO2. The Heartmate II appears to have become the dominant player among destination LVADs, and accumulating experience shows substantially better durability with fewer complications as compared to the pulsatile Heartmate devices that previously dominated destination LVAD implantations. In a prospective comparison among 200 destination LVAD patients, Slaughter et al. recently reported a 58% two-year stroke free survival rate using the nonpulsatile Heartmate II, as compared to 24% for the most current version of the pulsatile Heartmate pump (Heartmate XVE) (Slaughter 2009). Heartmate II can generate flows up to 10 L/min, but it does require traditional anticoagulation rather than just aspirin, i.e., typically heparin or a direct thrombin inhibitor for perioperative “bridging.” Clinical trials will soon begin for an impeller-driven pump (MVAD for Miniature VAD, HeartWare, Inc., Miramar, FL) that displaces only 15 mL of blood and can be implanted in the pericardium without an external pocket. This pump runs at very high RPMs, generates over 5 LPM flow in calves, and may not require anticoagulation (Slaughter 2009 B). This pump could potentially revolutionize destination VAD therapy. If a temporary RVAD is needed, the most commonly used pump is a nonpulsatile centrifugal unit called Centrimag (Levitronix LLC, Waltham, MA) (Bhama 2009). This pump can also be used as an LVAD or in series for both ventricles (BiVAD), typically as a bridge to transplantation. This pump generates up to 10 L/min flow, so it should be sufficient as an RVAD for almost any situation except pumping against very high PA pressures.

Anesthetic considerations. The considerations noted above for SVR mostly apply to VAD implantation as well. TEE is even more essential because one needs to diagnose and close any patent foramen ovale, diagnose and remove thromboses in the left atrium or ventricle, and diagnose and repair any aortic insufficiency (which can be devastating). In addition, TEE is used to assess for air evacuation, for appropriate VAD inflow and outflow characteristics, and for left and right ventricular filling and function. Often the initiation of LVAD flow unmasks RV dysfunction that may require aggressive pharmacologic management or even mandate the use of a right VAD as well. Often these patients experience a systemic “vasoparesis” after initiation of LVAD support, which requires the use of alpha-adrenergic agonists, vasopressin, or possibly methylene blue in order to sustain adequate systemic arterial pressures. Whereas pulsatile valved VADs are afterload insensitive (analogous to CPB with a roller pump), continuous flow VADs are afterload sensitive (analogous to CPB with a centrifugal pump), hence higher systemic vascular resistance levels can seriously compromise systemic blood flow even in the presence of normal systemic arterial pressures. Most of these patients will require mechanical ventilation at least overnight, so there is little advantage to fast-track anesthesia. Complex coagulation

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disturbances, anticoagulation regimens, and re-exploration for bleeding are fairly common. Over 50% of destination VAD patients experience abdominal complications (Bhama 2010), and just over a third of those patients will require abdominal surgery, so the potential to see a VAD patient in a noncardiac operating room is substantial. Patients with nonpulsatile VADs appear to be more susceptible to upper GI bleeding than patients with pulsatile VADs (Crow 2009). When patients with indwelling nonpulsatile VADs present for noncardiac or cardiac surgery, blood pressure and SPO\textsubscript{2} monitoring prove challenging when arterial blood flow predominantly passes through the VAD, as no arterial pulse is then present. Noninvasive BP measurements will be ineffective, and arterial catheter placement is complicated by the absence of a palpable pulse. In this scenario, ultrasound guidance facilitates placement of an arterial catheter. Doppler flow detectors can also be used with a traditional BP cuff and an anaeroid manometer to approximate mean arterial pressure. If there is any native pulsatility whatsoever (representing arterial blood flow through the aortic valve rather than the LVAD), pulse oximetry has a chance for success. When pulsatility is absent, a pulse oximeter may not detect a signal, and one might then consider transcutaneous cerebral oximetry for continuous monitoring of oxygenation.

**Temporary nonpulsatile percutaneous VADs.** Both cardiac and noncardiac anesthesiologists may benefit from some familiarity with the Tandem Heart percutaneous LVAD (pVAD), because this device is sometimes used to rescue patients with cardiogenic shock from a myocardial infarction or high-risk percutaneous coronary artery procedures that have gone awry. The potential involvement of anesthesiologists with these patients ranges from monitoring and urgent intubation up to general anesthesia for a deteriorating patient who needs completion of a stent procedure or a rescue sternotomy for CABG and/or cardiac tamponade. This centrifugal pump obtains venous return from the left atrium via the femoral vein and a trans-atrial septal puncture, and provides arterial return via the femoral artery to the approximate level of the aortic bifurcation (Kar 2006). The pump can deliver flows as high as 4 L/min, but it will fail if the lungs insufficiently oxygenate the blood or if the right ventricle is also failing. Tandem pVADs typically require heparin anticoagulation. We are seeing increasing use of this device at our referring hospitals as a means for stabilization prior to transportation to our established VAD center. The Tandem device will not suffice as a long-term VAD, and it may provide insufficient flow for patients with large body surface areas or very high systemic oxygen demands (e.g., septic patients).

The Impella 2.5 is a percutaneous VAD that is placed percutaneously via the femoral artery. This pump actually crosses the aortic valve and provides axial nonpulsatile flow (similar to the Archimedian screw principle) across the LV outflow tract and aortic valve into the proximal ascending aorta. Consistent with its name, the Impella 2.5 provides flows up to 2.5 L/min, hence it is useful for assistance but not as a means to replace full LV flow. There is also a larger Impella 5.0 VAD that provides flows up to 5.0 L/min and requires surgical placement via the iliac artery.
Mitraclip

Mitraclip (TM, Abbott Inc., North Chicago, IL) is a percutaneous device designed to reduce mitral regurgitation by transatrial septal placement of a “double alligator” clip at approximately the midpoints of the anterior and posterior mitral leaflets (Fukamachi). This technique simulates the Alfieri suture mitral valve repair technique that is performed using an open traditional or minimally invasive cardiac surgical approach with traditional or minimally invasive cardiopulmonary bypass. Mitraclip placement results in a double-orifice mitral valve that resembles a figure-of-eight. The technique has been prospectively evaluated in the EVEREST I and II trials and the short-term results have been favorable (Yuksel). As compared to a surgical mitral valve repair, the quantitative reduction in mitral regurgitation is less, but nonetheless substantial. Mitraclip placement is effective for either structural or functional mitral regurgitation as long as there is sufficient central leaflet surface to allow grasping by the clips (Fukamachi). A significant minority of patients require two clips. The surfaces of the clips endothelialize over time while seldom inducing mitral stenosis. The ideal Mitraclip candidate is an older patient whose surgical risk is high. Obviously patient selection is subject to interpretation and to shades of gray.

Acute problems during placement include procedural failure, worsening of mitral regurgitation, creation of mitral stenosis, creation of an atrial septal defect, and rupture of the right or left atrial walls to induce possible cardiac tamponade (Jilaihawi). Some of these complications require emergent surgery, which can be a problem if a cardiac surgeon has not been engaged in advance or if the rationale for the Mitraclip procedure is the patient’s unacceptability for or refusal of surgical intervention. Small series of Mitraclip patients who have required late surgical intervention primarily for residual mitral regurgitation (rarely for new mitral stenosis) indicate that open mitral valve repair is complicated by the presence of Mitraclips, yet repair remains possible for most patients (Argenziano, Geidel). The remainder of patients require mitral valve replacement, so some patients who receive Mitraclip intervention lose the previously viable option of surgical valve repair.

I was unable to find recommendations for anesthesia management other than categorical mention of general anesthesia being used (Feldman) and a case report demonstrating successful deep sedation in a patient with multisystem disease who had previously experienced prolonged intubation as a result of inability to reverse neuromuscular blockade after general anesthesia (apparently using d-tubocurare!) (Ussia). The need for near-continuous transesophageal echocardiography (TEE) combines with the anticipated duration of the procedure (most reports show 2-3 hours) to lead most anesthesiologists to select general anesthesia with an endotracheal tube, which is consistent with our experience at the University of Colorado. In addition, real-time three-dimensional TEE seems highly advantageous to the performance the procedure (Jilaihawi, Swaans). Additional monitoring should include an arterial catheter, which may or may not be feasible via the femoral artery depending upon whether the interventional cardiologist plans to place an introducer there. This is not required for the procedure, so we most
often place a radial artery catheter. Central venous access is a judgment call and pulmonary artery catheters are seldom needed.

Anesthetic considerations. Anesthesia principally involves implementation of the usual principles for management of mitral regurgitation (e.g., absence of bradycardia or vasoconstriction, appropriate but not excessive preload) along with a technique that will facilitate immediate extubation in the absence of pre-existing pulmonary edema or intraprocedural complications. There will be little post-procedural pain, so the use of shorter-acting anesthetic drugs makes sense. Remifentanil or alfentanil infusions are well-suited to these patients’ needs, but fentanyl or sufentanil either via bolus or infusion can also be used. The vasodilatory and short-acting nature of the potent inhalational agents desflurane and sevoflurane offer appeal, although sicker patients may not tolerate them in doses exceeding 0.5 MAC. Neuromuscular blockers are not required for maintenance of anesthesia, but may facilitate patient management.

Transcatheter Aortic Valves

Another emerging technique is transcatheter aortic valve replacement, which can be performed percutaneously (transfemoral artery) or transapically (Fassl 1). As with Mitraclips, the target population is patients with critical aortic stenosis who are at especially high risk for undergoing full or partial sternotomy with cardiopulmonary bypass (Grube). These patients typically have Society for Thoracic Surgeons (STS) risk scores exceeding 10, are octogenarians, and have aortic valve areas less than 0.8 cm$^2$ (Fassl 2). The valves compress to a size consistent with placement through a 22-24 French femoral arterial introducer, then are expanded by a balloon much like endoaortic or carotid stents, except that in this case the entire arterial circulation must be temporarily interrupted during placement. “Deadeye” placement accuracy is critical, because placement a little too far upstream places a normal aortic valve proximal to the intact critically stenotic one, while placement a little too far downstream risks occlusion of the coronary ostia (Fassl 1). Insufficient expansion, which results from insufficient balloon inflation, can induce aortic insufficiency, hence TEE is essential. Typically this situation can be managed acutely by balloon reinflation. The transapical approach requires general anesthesia and a small thoracotomy, but has a higher success rate (Fassl 1, Walther).

Anesthetic considerations. Monitored anesthesia care has been reported for the transfemoral approach, but most centers appear to use general anesthesia (Behan, Fassl 2). A hybrid interventional radiology suite/operating room maximizes flexibility when this approach is taken. If general anesthesia is used, then an endotracheal tube makes sense because of the use of TEE and the potential for hemodynamic deterioration. The usual considerations for aortic stenosis management apply (absence of tachycardia or vasodilation, sensitivity to adequate preload, optimal presence of atrial “kick”). Intra-arterial pressure monitoring is strongly advised, because of the temporary total obstruction of left ventricular output and the common use of either rapid ventricular pacing or pharmacologic sinus node arrest induced by high doses of
adenosine. Some prefer to administer alpha-adrenergic agonists prophylactically prior to this intervention. Central circulatory access is a judgment call, but does offer appeal. Often this can be provided via the “surgical” field via cannulation of the femoral vein. Anesthetic techniques similar to those noted for Mitraclip placement apply. Immediate extubation can typically be accomplished, but it should not be a “shocker” if these elderly, frail patients require postprocedural intubation for a variety of reasons: hypoxemia from pulmonary edema, impaired LV function requiring inotropic support, prolonged or complicated procedure, etc.

The transapical approach adds the likely need for collapse of the left lung to enhance surgical exposure, hence either a double-lumen endobronchial tube or a bronchial block is desirable (Fassl 2). Additionally, consideration should be given to postoperative analgesia techniques such as continuous thoracic epidural analgesia, continuous or single-shot paravertebral nerve blocks, or single-shot intercostal nerve blocks. Obtaining central venous access becomes more compelling when this approach is selected, especially since there may be no venous access via the groin. One should most often be able to extubate the trachea at the conclusion of the procedure. The procedure does not require cardiopulmonary bypass, but the need for temporary rapid ventricular pacing still applies, as do the potential proximal-distal positional and insufficient valve expansion misadventures. As for preparing a vasopressor infusion in advance, my personal preference runs to norepinephrine, because it seems best able to increase blood pressure without compromising cardiac output (because of its significant beta-agonist component, unlike phenylephrine) or causing tachycardia. Of course, this presumes that one can obtain norepinephrine (or even phenylephrine) in view of the ongoing critical drug shortages being experienced. Epinephrine might jump ahead of norepinephrine as my first choice when left ventricular ejection fraction is significantly compromised pre-procedure (e.g., 0.40 or below). Dobutamine is possibly more likely to be favored by interventional cardiologists, who may not appreciate its greater tendencies to induce tachycardia and to fail to increase arterial pressure.

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Ventricular Assist Devices
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Mitraclip

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