

Congestive Heart Failure Procedures

A variety of procedures address the growing demand for alleviating symptoms of congestive heart failure (CHF) and prolonging survival. These include surgical ventricular restoration, mitral valve repair, tricuspid valve repair, left ventricular aneurysmectomy, placing sock-like devices around the heart to restrict its dilation, temporary (bridging) and permanent (destination) ventricular assist devices, total artificial hearts, and cardiac transplantation. This constitutes a potential growth area for cardiac surgery, as over 500,000 new cases of heart failure present each year in the U.S. Medical management improves symptoms and survival, but not dramatically so. Cost-benefit and risk-benefit relationships for the various medical and surgical options unfortunately remain ill-defined.

Surgical Ventricular Restoration (SVR) is a not-so-new (but still investigational) procedure that has gained increased application based upon recent reinterpretation of cardiac geometry (Athanasuleas 2001A, DiDonato 1995, Dor 2001, DiDonato 2001, Athanasuleas 2001B, Athanasuleas 2002). The left ventricle (LV) contracts and empties better when it is elliptical than when it is spherical. Previous thinking was that the spherical shape associated with CHF ensued primarily as a result of diffuse cardiomyopathy or from end-stage triple-vessel coronary artery disease. After an extensive anteroseptal myocardial infarction that wraps around the apex, however, the heart's shape gradually evolves into a sphere, thereby tethering the adjacent viable inferior wall to render it functionally inept, as expressed by either akinesia or dyskinesia. (Athanasuleas 2001A, DiDonato 1995) A European group developed the Dor procedure (same as Surgical Ventricular Restoration) to address this issue (Dor 2001). Its principle is that **exclusion of the dead portion of the anteroseptal and apical areas will produce more elliptical geometry while allowing the tethered but viable inferior wall to resume functional contraction**. The results in uncontrolled studies have been striking, with 10-20% improvements in left ventricular ejection fraction accompanied by marked symptom improvement and improved survival as compared to the usual life expectancy without SVR (DiDonato 2001, Athanasuleas 2001B, Sartipy 2008). Interestingly, the anteroseptal and anterior areas need not be aneurysmal for patients to benefit from this operation. The operation involves opening the LV vertically parallel to the interventricular septum, manually determining the margin of viable myocardium, encircling the LV cavity from inside with a purse-string suture, sewing in an ovoid ring that typically contains Dacron or bovine pericardium, then closing the nonviable ventricle over the newly constructed synthetic LV apex (Athanasuleas 2002). Because these patients typically have marked LV dilation with congestive heart failure (CHF) and may have inducible ventricular tachycardia, the operation may also include mitral valve annuloplasty and/or LV endocardial resection or cryoablation (Dor 2001). Selective coronary revascularization (CABG) may also be needed (Dor 2001).

Anesthetic Considerations. Most of these patients have initial LVEFs below 30% and have symptomatic CHF, so they will be taking the usual array of medications that include an angiotensin converting enzyme (ACE) inhibitor or angiotensin receptor blocker, beta-adrenergic blocker, diuretic, and possibly digoxin and/or milrinone. Electrical cardiac aids such as implanted cardioverter-defibrillators and biventricular pacemakers are commonly present, thus creating the need for preoperative consultation with an electrophysiologic cardiologist and a game plan about the need for preoperative device deactivation and post-bypass or postoperative reactivation. Transesophageal echocardiography (TEE) is essential for the following reasons: 1. It may help the surgeon's decision about the optimal location for the apical patch, hence a detailed analysis of LV wall motion is needed prior to cardiopulmonary bypass (CPB). 2. It may help the surgeon decide about the need for mitral valve repair or replacement, and TEE would then assess the post-CPB success of the chosen mitral valve intervention. 3. Immediate post-CPB assessment of inferior LV wall motion adjacent to the patch will assess the appropriateness of the patch location, as one would expect the previously dyskinetic/akinetic inferior wall to begin thickening. Because this improvement may not be immediate, contrast-enhanced TEE could in some cases provide early feedback about patch placement and inferior wall viability. 4. Since the dead portion of the myocardium will cover the patch, leaks in the patch suture line may not be immediately evident to the surgeon. 5. Accurate LV preload assessment is needed after CPB, because these functionally impaired left ventricles poorly tolerate both underfilling and overfilling. Anesthetic technique involves recognition that poor LV function and CHF are the rule. My opinion is that **fast-tracking is generally infeasible** in this patient population, so I often choose to simplify the intraoperative period by reverting to higher-dose opioid techniques, e.g., 20-40 mcg/kg of fentanyl (Sun 2008A). Prophylactic beta-adrenergic blockade (often already in place preoperatively) may decrease the CPB-induced down-regulation of cardiac beta-receptors, so this is advisable if hemodynamics permit. The combined potential pre-CPB presence of

critical coronary stenoses supplying viable myocardium, mitral regurgitation associated with a dilated LV, and severely limited LV contractile reserve challenge clinicians to balance competing pathophysiologies in order to optimize preload, heart rate, and systemic vascular resistance. The anesthesiologist therefore needs to frequently assess these factors and make adjustments as necessary. After CPB, optimization of rhythm, preload, afterload, and LV contractility can also be challenging. Atrioventricular synchrony is very helpful, and resumption of biventricular pacing (if already in place) may also improve cardiac output. Assuming no active myocardial ischemia, having a heart rate in the 90-100 range may optimize stroke volume for the freshly-shrunk LV cavity as it begins its gradual remodeling. Most of these patients will require inotropic support. Typically dobutamine or epinephrine is chosen, and milrinone can complement either of those inotropes while keeping pulmonary and systemic vascular resistances from becoming excessively high. If low systemic vascular resistance (with or without milrinone) causes mean arterial pressure (MAP) to drop below 60 mmHg despite an adequate cardiac output, a vasopressor may also be needed. Increasingly we are selecting vasopressin for this clinical application, because it works well and probably preserves renal blood flow while averting increases in pulmonary vascular resistance better than phenylephrine or norepinephrine. Intra-aortic balloon pump support may be helpful or essential as well (Athanasuleas 2001B).

Ventricular Assist Devices. For the purpose of this lecture, principally left ventricular assist devices (LVADs) will be discussed. Clearly not everyone with severe CHF can receive the limited available number of cardiac transplants (approximately 2,500 per year in the US), and ventricular assist devices (VADs) are becoming more available and appealing. 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 2008B). **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 there is a strong potential for implantation of 20,000-60,000 VADs per year as so-called “destination” therapy (as opposed to short-term resuscitation or bridging to cardiac transplantation) for CHF, and yet that fewer than 500 implantations were 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. Further, the concurrent presence of several experimental VADs impairs the acquisition of sufficient numbers of patient implantations and long-term outcomes for any single device to attain FDA approval. In addition, technology continues to evolve faster than one could reasonably expect a governmental approval process to accommodate.

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 also 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 2008B). **This nonpulsatile mechanism is efficient but complicates and sometimes precludes noninvasive assessment of blood pressure and SPO₂.**

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 or vasopressin 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 disturbances, anticoagulation regimens, and re-exploration for bleeding are fairly common. When patients with indwelling nonpulsatile VADs present for noncardiac or cardiac surgery, blood pressure and SPO₂ monitoring prove challenging when arterial blood flow predominantly passes through the VAD, as no arterial pulse is present. Noninvasive BP measurement will be ineffective, and arterial catheter placement is complicated by the absence of a palpable pulse. In this scenario, ultrasound guidance facilitates the essential placement of an arterial catheter. If there is any native pulsatility whatsoever (representing arterial blood flow through the aortic valve rather than the LVAD), pulse oximetry has some chance for success. When pulsatility is completely absent, the pulse oximeter may not detect a signal, and one might consider a modality such as noninvasive cerebral oximetry (despite some limitations) for continuous monitoring of oxygenation.

A New Vasodilator

A new short-acting vasodilator recently arrived on the American scene: **Clevidipine**. Structurally analogous to nifedipine and nicardipine, clevidipine is a calcium channel blocker with an **onset time of < 2 minutes and an offset time of < 5 minutes** (Ericsson 1999, 2000). Clevidipine does not accumulate, so its offset time is the same whether it has been infusing for 15 minutes or for 24 hours. It does not have active metabolites, and is metabolized in the bloodstream without dependence upon the liver or kidneys for offset of action. The dose range appears to be 0.2-5 ug/kg/min, but human clinical data remains insufficient to fully assess interpatient dose-response variability. Toxicity appears minimal, but long-term follow-up is lacking.

Aronson et al. conducted a large open-label clinical trial (Aronson 2008) comparing clevidipine (CLEV) to nitroglycerin (NTG), nitroprusside (NP), and nicardipine (NIC) in over 1500 patients undergoing cardiac surgery in 61 centers. Blood pressure reduction end points were left to local investigators; clevidipine dosing was by protocol, whereas NTG, NP, and NIC dosing was left to the investigators' judgment. The comparison between CLEV and NIC was limited to the postoperative period, whereas those between CLEV and NTG or NP included the preoperative and intraoperative periods as well. A target blood pressure (BP) range was identified and was then compared by area-under-curve analysis for each drug pairing. **CLEV produced BPs within the target range (over a range of definitions) more often than NTG or NP.** NTG patients had the greatest tendency to remain hypertensive, and NP patients had the greatest tendency to experience BPs either below or above the target range. There was no difference in BP control between NIC and CLEV. Outcomes and toxicities were recorded out to 30 days postoperatively, and unadjusted data showed a higher death rate among NP (4.7%) than CLEV (1.7%, P=0.04) patients, but this difference was rendered insignificant by adjustment for comorbidities and intraoperative variables. **This clinical trial, while impressive in size, had some study design features that raise concern:** the absence of a defined protocol for NTG, NP, and NIC administration may have biased the comparisons, and BP control end points were not prospectively established for the investigators even though the adequacy of BP control was analyzed within target ranges that were defined post-hoc. A much smaller (N=39) earlier prospective trial (Powroznik 2003) used structured dosing and defined end points for both CLEV and NP, and those investigators found no difference in the area-under-curve BP control analysis for the two drugs, but NP was associated with a slightly faster heart rate, lower filling pressures, and higher intravenous fluid requirements. These results reflect that CLEV shares NIC's lack of venodilation, whereas NTG and NP each induce substantial venodilation.

Whereas NP demonstrates almost equal venous and arterial vasodilation, NTG's venodilation exceeds its arterial vasodilation, therefore BP reduction from NTG may reflect reduced preload-dependent cardiac output more than a decrease in systemic vascular resistance. BP recovery times to within 10% of the original MAP (after 30% reduction) upon discontinuation of CLEV averaged 2.4 minutes, whereas the same recovery averaged 18.7 minutes for NIC, 3.9 minutes for NTG, and 0.6 minutes for NP (Nordlander 2004). Depending upon the potency of CLEV (which varies among studies), the drug acquisition cost per hour ranges from \$18-\$50, as compared to \$15-30 for NIC, and less than 30 cents for NTG and NP.

Summary: CLEV produces rapid BP control that is almost as rapidly titratable as NP with less preload reduction and possibly less BP volatility at a much greater expense and probably with less toxicity. Nevertheless, there is **an easy way to minimize NP's cyanide toxicity that seems seldom used: simply mix NP in a 1:8 ratio with thiosulfate** (i.e., 50 mg of NP in a combined infusion mixture with 400mg of thiosulfate) (Tasch 1983).

Central Venous Catheter (CVC) Placement with Ultrasound: Boon or Bane?

To cut to the chase: **it's a boon**. But is it such a boon that failure to use real-time ultrasound for every CVC placement should be considered heretical? Things seem to be moving in the direction of real-time ultrasound as a standard of care. Does the available evidence justify such a draconian approach? Let's examine the evidence.

Use of Doppler ultrasound (identifying the vein via its characteristic audible "hum") to localize the internal jugular vein was reported as early as 1978 (Ullman 1978). In 1991 Troianos et al. reported the use of B-mode (2D) ultrasound (BUS) to depict the anatomy of the right internal jugular vein (RIJ) (Troianos 1991). In a teaching hospital Troianos et al found that the use of ultrasound-guided RIJ puncture decreased the number of needle passes and the average time taken per cannulation. There was also an impressive trend toward a decrease in the incidence of arterial punctures (7 of 83 patients with standard approach, 1 of 77 with ultrasound). Since this important study, there have been numerous others comparing various aspects of ultrasound-guided RIJ cannulation to the traditional "landmarks" anatomic approach. Conditions of study and patient populations have varied considerably. Unsurprisingly, Schummer et al. showed a higher first-needle pass success rate using B-mode than Doppler ultrasound to locate the RIJ (Schummer 2006), so studies cited henceforth will be limited to B-mode ultrasound technique. Keenan reviewed the literature in 2002 (Keenan 2002), at which time he found 12 prospective studies comparing ultrasound to the anatomic landmark-based technique (LM) for RIJ cannulation in adults, but only 4 trials were clearly conducted on consecutive patients. Six of those studies compared BUS to LM techniques, but only the Troianos study routinely involved anesthesiologists or cardiac surgery patients, and five used supervised residents or fellows as the primary operators. Only the studies of Denys et al. (N=604) and Troianos et al. (N=160) investigated more than 100 patients (Denys 1993, Troianos 1991). Some aspects of Keenan's pooling of data are questionable, in that he combined adult and pediatric trials as well as Doppler and B-mode ultrasound trials. Nevertheless, ultrasound consistently reduced the number of needle passes required for initial venous blood "flash," and cannulation failure rates. With respect to the time taken for IJ cannulation, various studies favored either BUS, LM, or neither technique. Only the study of Denys et al. found a statistically significant difference in arterial puncture rate (BUS 8/302, LM 25/302). A 2003 meta-analysis by Hind et al. (Hind 2003) had similar findings to those of Keenan, and also indicated that the data on the use of US vs LM techniques for cannulation of the subclavian or femoral veins in adults were inconclusive. With one exception (Karakitsos 2006), **studies to date lack comparative analysis of outcomes such as central-venous catheter sepsis, pneumothorax, and clinically significant cervical hematomas for BUS versus LM IJ cannulation techniques**. Stroke, mortality, and cost-effectiveness comparisons are either nonexistent or inconclusive.

Several additional studies have been published since 2003. In a retrospective study of 484 IJ cannulations performed in an ICU mostly by junior residents supervised by senior residents, Martin et al. found no significant difference in complications between BUS and LM techniques (Martin 2004). In a study where radiologists randomly used BUS and fluoroscopy to place emergency IJ dialysis catheters, Koroglu et al. needed fewer needle passes with BUS and significantly reduced the arterial puncture rate from 35% (!) with LM to 0% with BUS (Koroglu 2006). This suggests that radiologists are highly skilled with imaging techniques less so with "blind" anatomic techniques. Using emergency room attending physicians or residents for IJ cannulation in 130 patients, Leung et al. achieved higher first-pass success with BUS than LM, with a carotid puncture rate of 4/65 using LM and 1/65 using BUS (apparently NS, but overall complications were significantly reduced with BUS) (Leung 2006). Milling et al. randomly assigned 201 emergency room patients to either real-time BUS, static BUS (i.e., scan and mark IJ location prior to attempted puncture), or LM technique, and found that first-pass success, overall success, and time for cannulation were best with real-time BUS, next best with static BUS, and worst with LM (Milling 2005). There were 8 carotid punctures using LM and 2 each with real-time and static BUS (difference not significant). In 2006 Karakitsos et al. uniquely used attending physicians (cardiologists, intensivists, and surgeons) exclusively in a randomized, prospective study of 900 intensive care patients (Karakitsos 2006). BUS was superior to LM (top of the sternocleidomastoid triangle, ipsilateral nipple needle trajectory) in overall success in cannulation, number of attempts required for cannulation, carotid artery puncture, hematoma formation, pneumothorax rate, and

catheter-associated blood stream infection. In a teaching hospital using predominantly first- and second-year anesthesiology residents to perform IJ cannulations, Augoustides et al. found that both needle-guided BUS and non-needle-guided BUS resulted in a 4-5% carotid puncture rate without clinically important sequelae (Augoustides 2005).

Most studies comparing BUS to LM techniques have noteworthy limitations. First, **the LM technique commonly either varies within the same study or is inadequately described.** This aspect and the lack of clear consensus about the best LM technique to minimize needle passes, failed cannulation, and arterial puncture place the LM technique at a disadvantage in most comparisons. Second, **most studies used trainees predominantly or exclusively,** and some studies show that the advantage of BUS over LM is accentuated by operator inexperience. Third, **some studies showing BUS superiority had unacceptably high arterial puncture rates with the LM technique.** Over a period of decades, the LM technique has most often produced an arterial puncture rates of 5% or less (even with trainees), so arterial puncture rates exceeding 10% suggest operator inadequacy with the LM technique. Further, although carotid puncture is clearly undesirable, most do not result in clinically significant complications. Fourth, the absence (to date) of biplanar or 3D scanning for IJ puncture places the BUS operator at some disadvantage, because transverse (coronal plane) scanning may fail to identify the needle tip and longitudinal (sagittal plane) scanning most often fails to simultaneously image the carotid artery and the IJ vein, and there typically is insufficient room to place the probe above the clavicle while leaving space below the mandible for the IJ cannulation procedure. Finally, **no study has compared BUS to LM when IJ cannulations were exclusively performed by anesthesiologists who had completed residency training.** As a corollary, there is insufficient evidence to make a reliable recommendation about the merits of static precannulation anatomic assessment of the IJ/carotid anatomy to those of real-time scanning using experienced operators for both techniques.

Nevertheless, much has been learned from BUS studies of IJ cannulation, to wit,

1. Anatomic variations on the position of the IJ relative to the carotid artery are surprisingly frequent and often frightening,
2. The RIJ can be either so small or so clotted as to warrant a first cannulation attempt elsewhere.
3. The less one rotates the head away from the side of intended IJ cannulation, the less the IJ overlaps the carotid artery.
4. The IJ is extremely compressible, to the extent that it may be difficult to avoid so-called double-wall IJ penetration with absence of blood “flash” until the needle is slowly withdrawn (even if it is slowly advanced). When the IJ predominantly lies anterior to the carotid artery, this becomes especially worrisome, and suggests the need for either an alternative site (left IJ or subclavian vein) or an alternative needle trajectory (e.g., medial-to-lateral).
5. Unsurprisingly, Trendelenberg’s position and the ValSalva maneuver substantially increase the diameter of the IJ without affecting the diameter of the carotid artery.

To what degree are anesthesiologists embracing the use of ultrasound for IJ cannulation? Bailey et al. surveyed cardiothoracic anesthesiologists in 2006, and found that two thirds of respondents never or almost never used ultrasound for IJ cannulations (Bailey 2007). In a survey of United Kingdom pediatric anesthesiologists, Tovey and Stokes found that only 26% of pediatric anesthesiologists always used ultrasound for IJ cannulation (Tovey 2006). These findings are interesting in view of recent recommendations. In a 2003 review article in the New England Journal of Medicine, McGee and Gould recommended that ultrasound guidance be routinely considered for IJ cannulations (McGee 2003). In 2007, Feller-Kopman recommended that chest physicians and intensivists “embrace the broad clinical applications of ultrasound,” stopping just short of recommending its routine use for IJ cannulation (Feller-Kopman 2007). In 2002, the British National Institute for Clinical Excellence recommended 2-D imaging as the preferred method for insertion of IJ central venous catheters in adults and children in elective situations. On the North American side of the “pond,” in 2001 the Agency for Healthcare Research and Quality recommended the use of ultrasound for central venous cannulation as one of 11 practices to improve patient care. Therefore, **despite substantive limitations in the quality of the scientific literature, regulatory and safety advisory agencies have boarded the ultrasound bandwagon on the subject of central venous cannulation.**

Conclusion: Despite the absence of sufficient well-designed comparison studies of BUS and LM techniques in the hands of ideally experienced operators, it seems reasonable to require that B-mode ultrasound be available in all anesthesiology settings where central venous cannulation is frequently performed. For elective IJ cannulations, it

also seems reasonable to expect that attempts be made to scan the anatomy of the IJ and carotid artery either immediately before (static) or during (dynamic, real-time) cannulation. Should existing ultrasound device(s) currently be in use elsewhere or should the need for central venous cannulation be urgent or emergent, the practitioner should use his or her own judgment about whether to proceed with a LM technique or await the availability of an ultrasound device. When the LM technique is used, strong consideration should be given to “crossing over” to real-time BUS if more than two needle passes are required to identify the IJ vein. Because of soft clinical outcomes, low numbers of patients, and suboptimal study design in most comparison studies to date, I do not believe it is appropriate to mandate the use of ultrasound for IJ cannulation as a minimum standard of care at this time. I suggest this despite a personal preference for its routine use.

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