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Anesthesia for Major Vascular Surgery

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I. INTRODUCTION

Patients scheduled for aortic reconstructive surgery are often at increased risk due to: Patient medical condition and surgical Procedures.

A. Patient medical condition

Most of the pathology is due to diffuse atherosclerosis, a systemic progressive disease that can cause: Arterial plaque enlargement, arterial embolism, or complete occlusion of circulation. The plaque location is often at the bifurcations where turbulent flow might exist. Mostly at the carotid coronary arteries, iliac arteries, aorta and superficial femoral artery. The symptoms might vary with the site and degree of the lesion. Intermittent claudication, rest pain, ulceration, or gangrene is all described. The patients are often older; most of these patients suffer from generalized atherosclerotic cardiovascular disease. Therefore, many of their other systems and organs may be affected as well. They have increased incidence of hypertension, diabetes and coronary artery, myocardial, valvular heart, renal, respiratory and cerebral vascular diseases.

B. Surgical procedures

Elective surgical intervention (open or endovascular) is usually indicated for abdominal aortic aneurysms more than 5 cm in diameter (>5.5 cm for TAA), those growing by more than 1 cm yearly (3 mm yearly for TAA) as well as for symptomatic aortic aneurysms. Surgical procedures are often involved in potential for blood loss embolization and/or major volume shifts. Organ preservation is often a concern due to periods of interruption in organ perfusion.

It is imperative, therefore, that the anesthesiologists perform special risk assessments on all these patients.

II. PERIOPERATIVE EVALUATION

A complete history and physical examination are mandatory, including system review, selected laboratory tests, and medication review with special emphasis on daily medications because many can interact with anesthetics. Most anesthesia-induced morbidity and mortality is related to the cardiovascular system; therefore, it is obligatory to perform a special risk assessment for this system.

A. Risk assessment

The American Society of Anesthesiologists, relying on the Drips classification, found that general physical condition correlates with surgical outcome. Similar correlation was found with the New York Heart Association classification where patients in Class 3 or 4 had a six to ten-fold incidence of mortality. Other factors included were history of nitrates intake, dyspnea on excretion, angina, aortic stenosis, advanced age, aortic surgery, emergency operation, dysrhythmias, CHF, and myocardial infarction. According to Mangano, the last three dysrhythmias, left ventricular dysfunction and myocardial infarction are the most important prognostic factors in risk assessment.

Others revalidated the Multiple Risk Index (MRI) but modified the importance of factors such as angina, hypertension, diabetes, non-Q-wave infarction, uncomplicated recent MIs and extensive MIs. Also were added: left ventricular hypertrophy, digoxin intake or aortic reconstructive surgery.

B. Evaluation of ischemic heart disease

Patients with congestive heart failure and some of the signs and symptoms of chronic heart failure should first be treated with diuretics, digitalis, or inotrope until they attain optimum and stable function. Several authors describe the association between CAD and vascular disease. As a result, perioperative myocardial infarction (PMI) can be as common as 6 to 20% during vascular surgery. The majority of patients, diabetic as well as non-diabetic, can have undiagnosed CAD or silent perioperative myocardial ischemia (SMI). Muir recommended Holter monitoring to detect patients at high cardiac risk. Patients with SMI were more likely to have impaired left ventricular function (<40% ejection fraction). Further heart investigation, such as ambulatory EKGs, or cardiac stress tests (exercise, dipyridamole, and thallium) were all suggested. A two-dimensional echocardiogram with dipyridamole, dobutamine, or color Doppler measurements, was also recommended. More sophisticated diagnostic methods, such as positron-emission tomography (PET) or single photon-emission computed tomography (SPECT) can provide information about the heart's metabolism as well as about its blood supply and mechanical function.

C. «Guidelines for Perioperative Cardiovascular Evaluation for Non-Cardiac Surgery» (The American College of Cardiology/American Heart Association 1994, 1997, 2002, 2007).

The purpose of the guidelines was to provide a framework for considering cardiac risk of non-cardiac surgery in various patients and operative situations. It stresses: 1. The need for communication among patient, primary-care physician, anesthesiologist, surgeon, and the medical consultant. 2. Preoperative testing should be limited to circumstances in which the results will affect patient treatment and outcomes. 3. A conservative approach to the use of expensive tests and treatments. 4. Define the patient's functional capacity, age, co-morbid conditions (DM, PVD, CRF, and COPD) and types of operation (AAA, TAA, and head and neck surgery). 5. List the Clinical Predictors such as: a. Major: -- Unstable coronary syndromes, recent MI, decompensated CHF, significant arrhythmia or severe valvular disease. b. Intermediate: -- Mild angina pectoris, prior MI compensated or prior CHF or diabetes mellitus. c. Minor: -- Advanced age, abnormal ECG findings (LVH, LBBB, ST-T abnormalities), rhythm other than sinus (ie: AF), low functional capacity, history of stroke and uncontrolled systemic hypertension.

In summary, numerous methods can be used to stratify high-risk cardiac patients before major vascular procedures. Most authors recommend a combination of history, physical examination, and non-invasive and invasive tests. Patients with diabetes, angina, a Q-wave on EKG, ventricular dysrhythmia, and age above 70 years are likely to have perioperative cardiac complications. Patients with all or none of these clinical risk factors will not benefit from further invasive or non-invasive tests; patients with two or three of these risk factors can benefit from further tests. There is no complete agreement as to the best tests to be performed on this group. A practical approach is to proceed from simple to more complex testing.

III. ANESTHETIC MANAGEMENT:

When determining the equipment, monitoring, and anesthetic to be used in this procedure, the risk status of the patient and the potential intraoperative hemodynamic changes, including excessive blood loss, must be considered.

A. Monitoring

Preparation in the operating room should include large; multiple intravenous accesses a five-lead EKG, and computerized continuous ST-T segment evaluation. Arterial blood pressure should be monitored with an in-dwelling arterial catheter that will also allow periodic measurements of arterial blood gases. A ST change indicating myocardial ischemia is strong predictors of perioperative MI. Postoperative ischemia is a significant predictor of long-term MI and cardiac death. Use of computerized ST-segment analysis in appropriately selected high-risk patients may improve sensitivity for detection of myocardial ischemia.

Central venous pressure catheters or Swan-Ganz catheters are used to monitor adequate volume replacement. The ASA believes that the following 3 variables are particularly important in assessing benefit versus risk of use of PAC: 1) Disease severity, 2) Magnitude of anticipated surgical procedure, 3) Practice setting. The patients most likely to benefit from use of PAC perioperatively are those with: 1) Recent MI complicated by CHF, 2) Severe CAD who is undergoing procedures associated with pronounced hemodynamic stress, 3) Systolic or diastolic LV dysfunction, 4) Cardiomyopathy, and 5) Severe valvular disease. We recommend cannulating with a Swan-Ganz catheter every patient with a] poor left ventricular function, b] recent myocardial infarction, c] unstable angina, d] intractable CHF, e] preoperative renal insufficiency, f] renal revascularization, or g] thoracoabdominal aneurysm. With the improvement of transesophageal echocardiography (TEE), some suggest that TEE is more sensitive than ST-segment analysis in detecting myocardial ischemia. Left ventricular regional wall motion and ejection fraction correlated well with the incidence of myocardial ischemia. But the largest experience to date suggests that the incremental value of this technique for myocardial ischemia risk prediction is minimal.

B. Choice of anesthetic

The American College of Physicians has recommended administration of β-adrenoceptor antagonists to patients with coronary artery disease undergoing surgery. To date, β-adrenoceptor antagonists are the only well-established means of prophylaxis against myocardial ischemia that demonstrates a reduction of morbidity and mortality in this patient population.

There is no scientific evidence to support the use of any one anesthetic technique for major vascular procedures. Intravenous narcotics are better at preserving cardiac output and blood pressure, and adding inhaled anesthetic helps to control hypertension but can cause myocardial depression. Most drugs should be titrated carefully because their affect on the geriatric atherosclerotic patient is unpredictable. Similarly, evidence favors neither general nor neuraxial techniques over the other for vascular surgery. One should still decide on the basis of personal clinical experience.

C. Aortic cross-clamping and declamping

One of the most destabilizing events during aortic reconstructive surgery is the clamping and unclamping of the aorta. Clamping the aorta interrupts blood flow to major organs, directly or indirectly causing hemodynamic and metabolic changes. These changes are highly visible with more proximal occlusion.

1. Hemodynamic changes

In the 70's and 80's, Silverstein and Attia described in detail the physiologic cardiovascular changes occurring during aortic cross-clamping. Increase in after-load, MAP, SVR, LVEDP, depression of cardiac output and LVSWI are usually happening while pre-load, CVP, PEDP can go up, down or remain unchanged. Peripheral vasodilatation with nitroglycerin or sodium nitroprusside has been suggested to attenuate the hemodynamic response.

2. Metabolic changes

Dr. Gelman described in a review article in 1995 all the metabolic changes that might occur with aortic cross clamping and declamping (Table I).

Most metabolic changes are reversed gradually after declamping, but the acidosis that increases during the clamping time can reach new highs with the flushing of ischemic tissue. Several authors have suggested the use of continues bicarbonate drip throughout the clamping specially in TAAA repairs. «Declamping shock» appears to be caused mostly by volume depletion and decreased venous return but many mediators were implicated in the hemodynamic and metabolic changes. The gradual release of the aortic clamp, volume loading, and correction of acidemia, hyperkalemia, hypocalcemia, and inotropic support of cardiac output are all effective during declamping.

D. Organ preservation

1. Spinal cord preservation - The blood supply of the spinal cord is made up of 2 posterior spinal arteries (originating from the vertebral or posterior inferior cerebellar artery) and one anterior spinal artery. From the caudal end, the anterior spinal artery receives arterial collateral supply from the internal iliac artery and its branches, the middle sacral artery, and the inferior mesenteric artery, while the thoracic portion of the anterior spinal artery is supplied segmentally by radicular branches of the intercostal arteries.
   The largest of the radicular branches, the artery of Adamkiewicz (arterial radicularis magna), arises directly from the aorta at T9-T12 in the majority of cases, but can arise anywhere between T5 and L5. Exclusion of this artery during aneurysm stenting can result in paraplegia. The mechanism by which damage to the spinal cord can happen is in the table II. Several techniques have been suggested to minimize anterior spinal cord ischemia: hypothermia, spinal cord drainage, arterial shunting, and pharmacological agents including papaverine, scavengers, and «spinalplegic» solutions. Several monitoring techniques can detect patients at risk, including somatosensory-evoked potentials, motor-evoked potentials, and angiographic or other visualization methods for identifying the arterial radicularis magna.

Table I. Metabolic changes.

Acidosis	Oxygen free radical	Myocardial depressant factor	Angiotensin	Interleukin-1,6
Lactate	Hypoxanthine	Endotoxins	Renin	Hypophosphatemia
Hypercarbia	Xanthine oxidase	Cytokine	Epinephrine	TxA2 Synthesis
Hypocarbia	Purines	Tumor necrosis factor (TNF)	Norepinephrine	Prostaglandin
Bradykinin	Endothelin-1	Anaphylatoxins	Histamine	

CSF drainage is the only method as of to date, that is routinely used for spinal cord protection.

Spinal cord perfusion pressure (SCPP) = mean arterial pressure (MAP) – cerebral spinal fluid pressure (CSFP). Cerebrospinal fluid drainage will increase SCPP by decreasing CSFP.

While several randomized controlled trials documented the possible efficacy of CSF drainage in open repair of TAA, evidence to support the efficacy of lumbar CSF drainage with EVAR procedures is limited.

2. Renal preservation – Renal failure is as prevalent as in 7% of aortic surgery (see table II). The use of mannitol, dopamine or verapamil and fenolpopam were all suggested, but the most widely accepted method is to maintain adequate volume throughout the surgical procedure.
3. Lungs - micro embolism of thrombi, atheroma or tissue debris following aortic clamping, can cause increase pulmonary vascular resistance both directly and through humeral factors such as TxA2 or anaphylatoxin. Increase in vascular permeability and congestive heart failure can bring increase in lung-water content and pulmonary edema. Postoperative respiratory failure is as common as in 26% of patients after TAA. The pathophysiology is not always clear and it is multifactorial. Direct instrumentation, ventilatory barotrauma or lung atelectasis (due to increase intra-abdominal pressure or pain-hypoventilation), can all contribute to organ failure.
4. Cardiac – since the incident of heart disease and specifically CAD is high in the vascular patient population (see pre-op evaluation), it is imperative to continue the cardiac medications intra-op especially beta blocked. But data are insufficient to determine whether Prophylactic administration of nitroglycerin is beneficial. Any sign of myocardial ischemia should be treated aggressively with NTG, beta- blocked and or neosynephrine as indicated by vital signs. Cardiac preservation and tight monitoring should be done during unstable stages of aortic surgery; aortic clamping, unclamping or blood loses.

   In patients with any history of CAD, obtaining ECG at baseline, immediately after the procedure, and for the first 2 POD is cost-effective. Postoperative ECG changes, increase of MB-CPK, increase of troponin-I and troponin-T should all be followed closely.

IV. ENDOVASCULAR AORTIC REPAIR

A. Introduction

Since the introduction of endovascular repairs, it had problems with migrations, endoleaks and durability. In recent years, though, the improvement in the endovascular stent grafts have helped to expend the use of endovascular repairs to a wide variety of cases. We now use endovascular surgery also in repairs of aortic dissection, trauma and aorto-deudenal fistulas and aortic aneurysm rapture.

Aortic arch and descending aorta are being repaired using a hybrid several staged operation which combines open and endovascular approaches.

These new indications require special anesthesia/surgery planning and set-up. TEVAR, calls for spinal protection with spinal fluid drain. Endovascular operations at the aortic arch often need balloon deployment with cardiac arrest. Hybrid and two staged operation were also introduced to allow for more complex endovascular surgeries. We are going to review the specific anesthesia management challenges caused by some of these advances procedures.

B. Surgical procedures to expand the eligibility for endovascular stent grafting

1. Ilio-conduit

If the femoral vessels are small in diameter, are heavily calcified or highly tortuous. A Dacron graft conduit is generally sewn onto the common iliac artery or aorta to be used as for the introduction sit of the endograft.

Table II. Renal preservation.

AX-c Time (min)	Paraplegia %	Renal failure %	Anterior-Spinal-Artery-Syndrome (Mechanism)
0-15	0	0	1. Injury to radicular artery by clamp
16-30	3.5	4.2	2. Radicular artery is distal to Ax-c
30-45	10	7.8	3. Areria Magna is inside the aneurysm
40-60	12.5	6.3	4. Prolonged Ax-c
>60	25		5. Prolonged hypotension
		Livesy 1985	6. Thrombosis of lumbar collateral

2. Hybrid procedures

When major branches originate from the aorta at the aneurysms level, it is necessary to secure continuation of blood supply to the effected organs prior to the aortic repair. This is called «hybrid» because it involves both open and endovascular operations, done in 1 or in 2 stages. It was, developed to expand the «anatomic» suitability for endovascular stenting and it typically less invasive than traditional open surgical repair. Some examples are:

a. Left carotid subclavian bypass: to allow a lending area of the TEVAR proximal to left subclavian artery.
b. Staged elephant trunk procedures: Stage I elephant trunk procedure may be performed to treat the proximal aortic pathology and create a proximal landing zone using cardiopulmonary bypass. This is followed at a later setting with the second stage endovascular repair utilizing the elephant trunk graft as the proximal landing zone.
c. Aortic Visceral De-branching: connecting visceral vessels to branches above or below the aortic endograph area before deployment. Example, left iliac system or infrarenal aorta to the left renal artery, SMA or celiac axis.

C. Anatomic requirements for EVAR

Aortic imaging can identify patients with aortic anatomy that either precludes the use of endovascular stents, requires the use of custom fenestrated or branched stent grafts, or necessitates the use of staged and or hybrid procedures. Proximal aneurysm neck requires > 15 mm- Length, < 30 mm-Diameter and less then 60 degrees angulation. The distal landing zone also has to be adequate in diameter and length. The Iliac arteries have to be patent and none-aneurysmatic. Access arteries (femoral) haves to be free of occlusion and adequate in size.

D. Choice of anesthetic management

Some centers perform EVAR procedures outside the operating room suite (i.e. interventional radiology or cardiology suite) where immediate expert help, access to blood bank or operating room may not be available. In my opinion, this practice should be discouraged.

The goals are to maintain hemodynamic stability, and preserve perfusion to vital organs including the brain, heart, spinal cord, kidney and splanchnic vessels. EVAR has been safely done using local infiltration anesthesia, central neuraxial blockade (spinal, epidural) as well as general anesthesia.

1. Local anesthesia with monitored anesthesia care (MAC): not always recommended since it is difficult to protect the stress response mechanism. Also the patient has to be able to breath in supine position and hold his breath when asked. The operation should be strait forward; good aortic anatomy, easy arterial access, and predicted shorter operation (<1-3 hours).
2. Regional anesthesia [(RA)-Spinal/Epidural]: As with the rest of procedures, there is no scientific evidence that regional anesthesia has any effect on patient's outcome. But our clinical bias is that especially in patients with Hx of CHF, COPD and or renal insufficiency; regional anesthesia might lower the incidence of perioperative morbidity. Same limitation of MAC can apply to RA. In addition, the need for evoke potential; TEE, illio-conduit or temporary cardiac arrest during the TEVAR can preclude the use of RA.
3. General anesthesia (GA): Is used more frequently due to the newer, more complex endovascular surgery. GA is indicated in longer stages, fenestrated, branched TEVAR, aortic arch repairs requiring balloon graft deployment with cardiac arrest and when TEE or evoke potential is, (SSEP and MEP) are in use.

Regardless of the type of anesthesia and the location of surgery, the monitoring should be kept invasive and similar to the open repair.

E. Intra-operative challenges (to be discussed in details)

- Surgical Bleeding: (may be occult) from small branches, iliac, femoral, aorta or any of the splanchnic arteries.
- Reperfusion massive edema and acid-bass imbalances: especially metabolic acidosis and hypotension following reperfusion of ischemic end-organs.
- Perioperative myocardial ischemia, tamponed, embolization and arrhythmias, directly related to guide wire manipulation near the aortic arch.
- Retrograde Type A aortic dissection during TEVAR
- Itrogenic temporary cardiac arrest/hypotension/bradicardia, in order to facilitate arch deployment. This is achieved by either intravenous injection of adenosine, rapid pacing or right atria inflow occlusion. Less invasive methods inclued the use of esmolol, sodium nitroprusside, nitroglycerin or clevidipine as needed.

F. Complications of EVAR

1) Procedure related complications include; Bleeding, iliac-femoral lacerations, access failure, need to conversion, leak to aortic sack, dissection of aortic wall, and/or aortic rupture. Similar to open repair, cerebral, cardiac, renal, spinal, intestinal or limbs injuries can occur with EVAR.
2) Late complications: Include device migration, endoleaks with/without aneurysm rupture and endograft infection. Endoleak is defined as the persistence of blood flow outside

the lumen of the endograft but within an aneurysm sac or adjacent vascular segment.

Classification of endoleaks

- **Type I.** Involves the proximal or distal seal zones. Further ballooning or placement of another graft may be necessary to achieve seal.
- **Type II.** Due to retrograde flow from intercostal arteries into the sac. Typically resolves with conservative management.
- **Type III**. Occurs with inadequate overlap and seal between modular components.
- **Type IV**. Occurs due to porosity of the graft, which is a rare occurrence with current-generation devices.
- **Type V**. Otherwise known as «endotension»,' occurs in the setting of continued sac expansion despite absence of an identifiable endoleak.

Types II and IV are considered benign, especially if not associated with an increase in aneurysm sac diameter, types I and III require interventions such as placement of extension stent to prevent aneurysm rupture.

G. Outcome

Despite the fact that EVAR is associated with less fluid shifts, absence of aortic cross clamping and a smaller surgical incision, it should be considered a high risk surgery. Most studies of EVAR Vs. open surgery have shown a reduction in short term mortality and morbidity, blood utilization and length of operation and hospitalization (EVAR-1, EVAR-2, DREAM, VA.). But this trend is lost over time and in 2-5 years the morbidity and mortality of endovascular equalizes to the open surgery. Actually, long-term complication and re-intervention rates were higher in the EVAR group in most studies. The idle population to benefit from EVAR is still unclear. The EVAR-1 trial suggests that the fittest can gain the most from EVAR. The Medicare group demonstrated that older patients can benefit the most from EVAR. The EVAR-2 study compared EVAR to medical treatment alone in patients that were not fit to go through open operations; it demonstrated no difference in outcome.

Most randomized trials reporting on intermediate and long term mortality only included EVAR. Despite promising results of TEVAR versus open repair in the reduction of perioperative morbidity, mid term results are less promising and large randomized trials addressing long term outcomes are still needed.

H. Postoperative management

Include assessment and management of modifiable risk factors for-CAD, CHF, HTN and stroke. Optimization of hypercholesterolemia, smoking, diabetes, physical inactivity, peripheral vascular disease, cardiac murmur, arrhythmia, conduction abnormalities, perioperative ischemia and postoperative MI. Patients who experience repetitive postoperative myocardial ischemia or sustain a perioperative MI have substantially increased risk of MI or cardiac death during long-term follow-up. Effective perioperative pain management (IV or epidural analgesia) leads to: Reduction in postoperative catecholamine surges and controls hypercoagulability response-both of which can theoretically contribute to myocardial ischemia.

V. IN SUMMARY

There is no complete agreement about the best preoperative evaluation techniques for risk assessment in major vascular procedures. Our emphasis is returning, perhaps, to the basic history and physical, although more sophisticated scanning techniques are also being developed.

Anesthesia and monitors are much improved and allow us to have more stable patients during induction, aortic cross clamping, and emergence from anesthesia.

Complication rates are decreasing in general, but no significant differences were found between regional and general anesthesia.

In spite of numerous studies, techniques for organ preservation are not yet satisfactory.

Endovascular aortic reconstruction surgery is gaining acceptance. These surgeries demonstrate better short-term outcome. Newer, more complex endovascular repair extend the use for stent repair and generate new challenges for the anesthesiologist.