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Choice of anesthetics

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The patient who presents for major elective vascular surgery is typically characterized by a history of atherosclerosis, hypertension, cigarette use, coronary artery disease, and diabetes mellitus. A combination of these clinical entities is often present and, depending of the severity of illness and state of control, these morbidities have an important impact on the choice of anesthetic technique.

A detailed preoperative assessment is one of the major contributing factors when choosing a safe anesthetic technique [1]. The kind and extent of the planned surgical procedure is another factor in choosing the anesthetic. The most challenging procedures are thought to be abdominal aortic aneurysm repair and major surgery of the ascending aorta, arch, and descending aorta; however, recent studies have indicated that even less extensive procedures such as peripheral vascular surgery can have considerable morbidity and mortality. Carotid endarterectomy (CEA) is considered to be a procedure associated with an intermediate level of risk.

Carotid endarterectomy

CEA has become a common procedure, with more than 100,000 procedures performed annually in the United States. Because carotid artery occlusive disease is caused by atherosclerosis, patients undergoing CEA generally have other ischemic vascular obstructions, including coronary artery occlusive disease.

The choice of anesthetic should therefore be aimed at protecting myocardial function and neurologic function. During surgery, patients often develop hemodynamic instability including hypertension during carotid artery clamping and hypotension during reperfusion after unclamping. During emergence from anes-

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thesia, tachycardia and hypertension can cause serious complications including myocardial ischemia and infarction [2,3].

Depending on the preference of the surgeon, CEA can be performed under regional or general anesthesia. Both techniques are acceptable, with the purpose of achieving intra- and postoperative hemodynamic stability and preventing the most common postoperative complications (Box 1) [4].

Regional anesthesia for CEA is advocated by some clinicians because of the possibility of continuous neurologic assessment, avoidance of general anesthesia (including tracheal intubation), and less hemodynamic instability. Surgery is performed under superficial or deep cervical plexus block with additional infiltration of local anesthetics by the surgeon with monitored anesthetic care [5]. Disadvantages of regional anesthesia can include restlessness, anxiety, and discomfort associated with prolonged procedures. Potential brain protection with general anesthetics cannot be provided.

Different anesthetic techniques have been described if a general anesthetic is administered. It is well recognized that almost all general anesthetics have the ability to protect the brain during ischemic conditions, mainly by decreasing oxygen demand (cerebral metabolic rate).

Historically, barbiturates such as thiopental have been administered with the assumption that barbiturates have cerebral protective properties because of free radical scavenging and membrane-stabilizing activity [6]. Conflicting outcomes studies have been presented concerning cerebral protection by barbiturates in focal ischemia [7,8]. In patients who have carotid artery stenosis and concomitant coronary artery disease, thiopental is not the induction agent of choice because of associated depressed myocardial contractility and hypotension with lowering of coronary perfusion pressure.

Propofol is reported to have free radical scavenging properties [9], but it often causes hypotension during induction by lowering peripheral vascular resistance.

Box 1. Common postoperative complications after carotid endarterectomy

- *Hemodynamic instability*
  - Hypertension
  - Hypotension
  - Myocardial ischemia and infarction
- *Hematoma and glossopharyngeal edema*
- *Respiratory insufficiency*
- *Neurologic dysfunction*
  - Acute graft thrombosis
  - Focal ischemia
  - Hyperperfusion syndrome

Hypotension can lead to decreased cerebral perfusion pressure. From the hemodynamic point of view, etomidate is the safest hypnotic agent, but it causes myoclonus approximately 1% to 2% of the time and pain at injection [10], both of which can be attenuated by the prior administration of opioids. Benzodiazepines such as midazolam should be used, if at all, at a low dose to prevent delayed emergence following surgery.

Anesthesia is maintained with total intravenous anesthesia (TIVA), an inhalation agent, or a combination of both. TIVA has been proposed as a method to achieve rapid postoperative recovery for neurologic assessment. Continuous infusion of propofol and remifentanil has been studied and shown to be satisfactory. Because of the tendency to cause hypotension, the dose of both agents has to be adjusted frequently during surgery, and often the additional administration of α_1-adrenergic agonists such as phenylephrine is required, which can lead to myocardial ischemia [11]. Instead of remifentanil, alfentanil can be used as an alternative short-acting opioid.

The use of inhalation agents, mainly isoflurane and sevoflurane [12], produces stable intraoperative hemodynamics, but the concentration at which isoflurane exerts maximal cerebral protective properties (2 MAC, MAC = minimum alveolar concentration) can cause serious, unwanted hypotension, requiring the use of α_1-adrenergic agonists to maintain cerebral perfusion pressure [11,13]. Sevoflurane and desflurane are similar to isoflurane in their ability to reduce cerebral oxygen consumption, but desflurane is less desirable because of its propensity to induce tachycardia. When inhalation agents are administered, fentanyl is administered routinely as an opioid, although this action might lead to prolonged postoperative respiratory depression.

In comparison with isoflurane/fentanyl, a propofol/remifentanil technique [14] is an attractive alternative, but apart from the expected lower incidence of postoperative nausea and vomiting it has not shown advantages with respect to more stable hemodynamics and neurologic outcomes [15]. Others report a lower incidence of tachycardia and hypertension during emergence in patients receiving isoflurane/alfentanil compared with propofol/alfentanil [13].

Inhalation agents have been reported to protect the myocardium against ischemia by means of preconditioning [16], but more studies will have to be performed examining their ability to protect the brain during ischemia by a similar mechanism [17].

Neuromuscular blocking agents (NMBAs) should be chosen to enable early postoperative extubation. Pancuronium, curare, and doxacurium should be avoided.

Abdominal aortic aneurysm

The patient who presents for elective repair of an abdominal aortic aneurysm often has additional hypertension (55%), coronary artery disease (73.5%), peripheral vascular disease (21%), stroke and transient ischemic attacks (22%), diabetes mellitus (7%), renal insufficiency (10%), and a smoking history (80%) [18]. The in-hospital mortality rate for surgery of infrarenal aortic aneurysm is reported to be 7% [19]. The choice of anesthetics might depend on concomitant disease, but no real difference in outcome has been shown between different techniques.

When TIVA is used, a combination of continuous infusions of propofol and short-acting opioids such as alfentanil and remifentanil is preferred. These combinations are particularly attractive when early postoperative extubation is planned. Because TIVA has no muscle-relaxing properties, higher doses of NMBAs are often required. TIVA with propofol or short-acting agents is also appealing in patients who have renal insufficiency or in cases involving suprarenal aortic clamping because of the lack of dependency on renal clearance for recovery.

There might be concerns about TIVA because of its tendency to cause hypotension, but hypotension can be abated by ensuring an adequate intravascular volume status before induction. In the presence of coronary artery disease, TIVA is probably less desirable because it might cause a decrease in coronary perfusion pressure.

Inhalation anesthesia, particularly in combination with opioids, is recommended. Moderate concentrations of isoflurane cause mild vasodilation, minimal myocardial depression, and reduce the need for NMBAs. Sevoflurane has even less pronounced hemodynamic effects, but there have been concerns about its use in patients who have renal insufficiency. Recent studies have shown no adverse outcome in patients who have chronic renal disease when exposed to sevoflurane for several hours [20].

The choice of NMBAs depends partly on the desire for early tracheal extubation, which is common practice in hemodynamically stable and normothermic patients. Vecuronium and rocuronium are indicated for this purpose, and cisatracurium is the agent of choice in patients who have concomitant renal insufficiency [21].

The use regional anesthesia in these patients is controversial. No difference in long-term outcome has been shown between general and regional anesthesia for abdominal aortic surgery [22], but in the short-term there is proof that regional anesthesia contributes to patient comfort, providing superior analgesia [23] and maintenance of pulmonary function [24,25].

When thoracic epidural analgesia/anesthesia is used intraoperatively, local anesthetics might induce sympathectomy, including hypotension and bradycardia [26]. A combination of opioids and smaller doses of local anesthetics can prevent these side effects. Patients should be switched to local anesthetics postoperatively.

Abdominal endovascular stents

Endovascular abdominal aortic aneurysm repair using a stent graft is a relatively new alternative to traditional open repair [27,28]. Shorter hospital stay and lower costs are the main advantages, but there is no significant difference in long-term outcome between the two treatment modalities [29]. Various types of anesthesia can be used for stent repair, specifically general anesthesia, regional anesthesia, and monitored anesthesia care with local anesthetic infiltration at the incision site [30,31]. Choice of anesthetic technique might be dependent upon the patient's coexisting diseases. General anesthesia is required if transesophageal echocardiography (TEE) is indicated for hemodynamic monitoring [32]. Although stenting is less invasive, serious complications such as ruptures with subsequent bleeding can occur [33].

Peripheral vascular surgery

Patients who present for arterial reconstruction of peripheral vascular occlusion often have generalized vascular disease including coronary artery disease, hypertension, and cerebrovascular disease. In addition, they often have diabetes mellitus and renal impairment. Usually they are long-time smokers and have chronic obstructive pulmonary disease (COPD). Although the surgical procedure might not appear to be as extensive as in abdominal aortic aneurysm repair, the clinical outcome of these procedures is often less favorable [34]. Perioperative myocardial ischemia often occurs, leading to myocardial infarction and mortality. The anesthetic technique should be selected with a goal of minimizing these complications. If general anesthesia is administered, a balanced anesthetic technique using inhalation agents, opioids, and NMBAs is preferred.

Anesthesia should be induced as if the patient was undergoing cardiac surgery, minimizing hemodynamic changes and preventing hypoxia. Tachycardia should be avoided because it is particularly detrimental [35]. Etomidate, vecuronium, rocuronium, fentanyl, moderate concentrations of isoflurane and sevoflurane, and nitrous oxide fit well within this spectrum. Low doses of benzodiazepines such as midazolam can also be added, although they might impede early tracheal extubation of the patient following surgery and contribute to the development of hypoxia [36].

Regional anesthesia is popular for these procedures, alone or in combination with general anesthesia. If epidural anesthesia is chosen, the use of a catheter for continuous administration of opioids and local anesthetics is indicated because reconstructive procedures might take considerable time. Though some studies have shown no myocardial benefits [37], epidural analgesia might be of benefit with respect to graft patency and survival. The results of different studies are conflicting, however, and no definite conclusion can be drawn. [38,39]. Bowel function might return more quickly postoperatively when epidural anesthesia is administered [40].

Surgery of the ascending and descending aorta

The underlying pathology in patients undergoing surgery of the aorta can essentially be divided in two categories: aneurysmatic dilation or dissection. Aneurysms are usually caused by atherosclerosis, inflammation, connective tissue disorders, or trauma. They can be located in the ascending aorta, aortic arch, or descending aorta. Thoracoabdominal aneurysms are classified according to Crawford (types I, II, III, and IV) [41]. Types I and II, which involve the proximal part of the descending aorta, have the highest morbidity and require the most extensive surgery. Surgery of aortic aneurysms is mainly elective unless uncontrolled bleeding is present.

Aortic dissections can be classified according to DeBakey (types I, II, and III) [42] or Dailey (type A or B) [43]. Typically, type III or type B dissections are treated medically unless continuous bleeding is not controlled sufficiently by lowering blood pressure and the patient becomes hemodynamically unstable. Type A dissections require urgent operative intervention; otherwise the outcome is fatal.

Patients who present with an aortic aneurysm based on a connective tissue disorder such as Marfan's syndrome or Ehlers-Danlos type IV are usually younger than 50 years of age and otherwise relatively healthy. Surgery is performed to prevent aortic root dissection and rupture in these patients [44]. The choice of anesthetic is probably not a decisive factor for outcome, which depends mainly on the extent of disease and the type of surgery to be performed. In corrections involving the ascending aorta and arch, deep hypothermic circulatory arrest is frequently applied [45,46]. A cerebral protection protocol including the administration of barbiturates before the start of circulatory arrest is often used [47]. Probably the most important goal for the anesthesiologist is to maintain stable hemodynamics, particularly avoiding hypertension. Isoflurane and sevoflurane might be advocated, keeping in mind their ability to protect several organ systems against ischemia by a mechanism of preconditioning.

When the surgical procedure is confined to the descending thoracic aorta, partial bypass is often used, keeping the patient normothermic. Although changes in blood pressure can be corrected by adjusting venous drainage into the bypass circuit, anesthetics that can be adjusted quickly are preferred. Nitrous oxide should be avoided because it might increase morbidity if an air embolism occurs [48].

During induction of anesthesia, it is important to realize that placement of a double-lumen tracheal tube, which is often used in surgery of the descending aorta, might require considerable time because the aneurysm often compresses or distorts the trachea or left mainstem bronchus.

During one-lung ventilation, the use of higher concentrations of inhalation agents is not recommended because of the possibility of inducing hypoxemia caused by intrapulmonary shunting.

The use of intraoperative epidural analgesia/anesthesia is controversial. Concerns regarding profound hypotension after unclamping of the aorta and regarding the development of an epidural hematoma as a potential complication in the presence of heparinization have restricted its application. Frequently, a thoracic epidural catheter is inserted before surgery and epidural analgesia/anesthesia is commenced in the early postoperative period.

The choice of NMBAs is important in patients who have renal dysfunction or renal failure. Typically, cisatracurium, which is cleared by Hofmann elimination and can be administered as a continuous infusion without a cumulative effect, is preferred in these patients [21]. To avoid tachycardia, vecuronium or rocuronium is preferred over pancuronium as long-acting NMBAs because of the lack of cardiovascular effects.

Emergencies

The most challenging patients in vascular surgery are those who present as emergencies (eg, ruptured aneurysm, dissection of the thoracic aorta, acute occlusion of peripheral arteries, and trauma).

Ruptured abdominal aortic aneurysm

A ruptured aneurysm of the abdominal aorta causes hypotension, anemia, and ultimately death. When the rupture is still contained, blood pressure might be normal and the only symptom might be pain. The choice of anesthetic technique for a ruptured abdominal aortic aneurysm is determined by the hemodynamic condition of the patient. In the case of profound hypotension despite vigorous fluid resuscitation, induction of anesthesia might cause deterioration in hemodynamic status because of vasodilation, which can be caused by [49]

- Reduction in sympathetic tone caused by loss of consciousness
- Vasodilation and myocardial depression
- Decreased venous return because of positive pressure ventilation
- Loss of tamponade after administration of NMBAs

A rapid sequence should be used to induce anesthesia, including adequate preoxygenation, cricoid pressure, and the use of succinylcholine. A low dose of an opioid such as fentanyl or alfentanil should precede a hypnotic agent to prevent tachycardia and an increase in blood pressure during laryngoscopy and intubation. Etomidate is preferred because of its favorable hemodynamic profile in comparison with propofol, thiopentathol, and midazolam. A low concentration of an inhalation agent can also be started, preferably sevoflurane because of its minimal vasodilatory properties. The choice of long-acting NMBAs is arbitrary because these patients are not usually extubated early postoperatively.

Before surgical clamping of the aorta, the hemodynamic condition of the patient might be unstable, requiring ongoing volume resuscitation and frequent adjustments of anesthetics, a strong argument for the use of inhalation agents instead of longer-acting opioids.

Acute aortic dissection: type A

Patients who present with an acute aortic dissection of the ascending aorta (type A) often receive antihypertensive medication intravenously such as sodium nitroprusside and esmolol to prevent the development of pericardial effusion and cardiac tamponade. Patients undergo emergency surgery, often with the use of deep hypothermic circulatory arrest, particularly when the distal arch is involved [50]. The surgeon often uses a combined approach to replace the ascending aorta and aortic arch and implant an elephant trunk [51]. The goal of the anesthetic technique is to prevent hypertension and tachycardia, particularly during induction of anesthesia. Because these patients generally have a history of hypertension, hypotension might cause profound impairment of organ blood flow, especially to the myocardium. Any antihypertensive medication has to be infused cautiously because it might amplify the vasodilatory properties of certain anesthetics. Etomidate is recommended to induce anesthesia. A balanced anesthesia technique including moderate doses of opioids, midazolam, and an inhalation agent is generally effective in maintaining hemodynamic stability.

In some instances a pericardial effusion is already present, indicating that complete rupture is eminent (Fig. 1), which represents an even greater challenge for the anesthesiologist because symptoms and signs of tamponade might dominate. Tamponade is often accompanied by right ventricular dysfunction because flow in the right coronary artery is compromised. Hypotension can induce insufficient coronary perfusion, and a small increase in blood pressure can cause total aortic rupture. Slowly administered, incremental doses of opioids, hypnotics, and NMBAs during induction of anesthesia and prompt treatment of hypotension and hypertension before, during, or after intubation should help stabilize the patient until cardiopulmonary bypass can be initiated.

Recently, the first stent placement in the ascending aorta for aortic dissection was performed. The anesthetic technique for it was similar to that used for an open approach. As demonstrated in Figs. 2–4, TEE is an essential monitor of verification of accurate deployment of the stent graft.

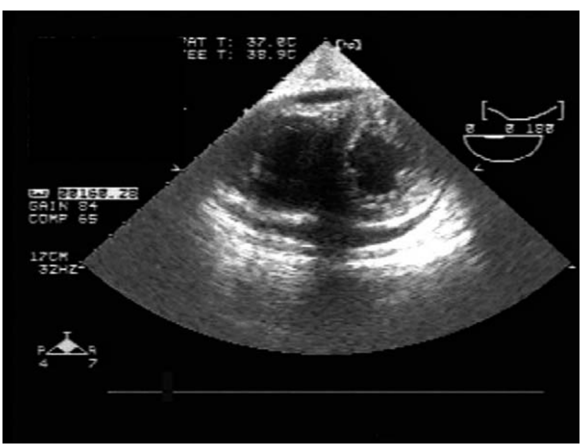

Fig. 1. Pericardial effusion during acute aortic dissection (type A).

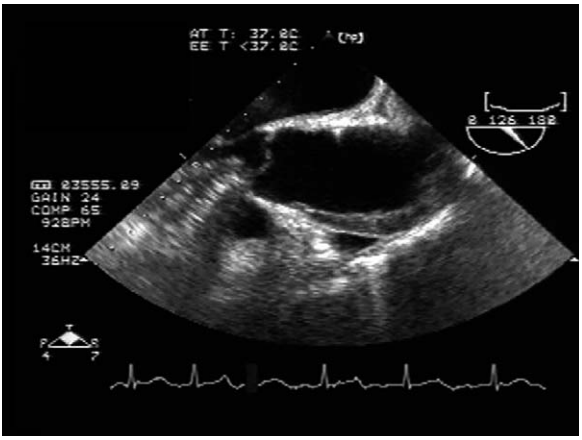

Fig. 2. Intramural hematoma with dissection in ascending aorta.

Acute aortic dissection: type B

Acute dissections of the descending aorta are generally treated medically, but in the case of a contained rupture and bleeding, emergency surgery is considered.

As with a type A dissection, the patient who has a type B dissection is treated with antihypertensive medication, but an additional challenge for the anesthesiologist includes one-lung ventilation in the lateral position. Surgery can be performed with or without the use of a partial cardiopulmonary bypass. The anesthetic technique is similar to that used for a type A dissection, but one-lung ventilation can cause hypoxia. Inhalation anesthetics that can induce intrapulmonary shunting should be used with caution.

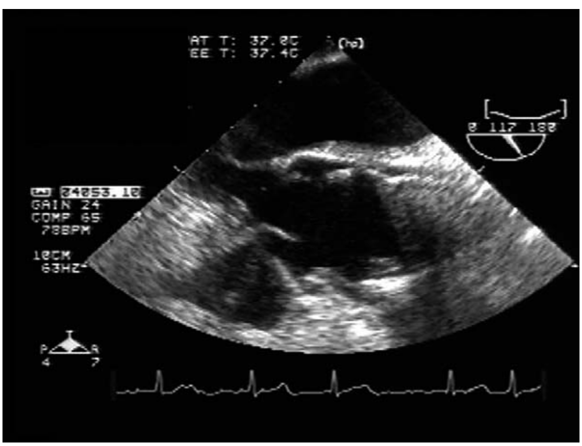

Fig. 3. Stent graft in ascending aorta.

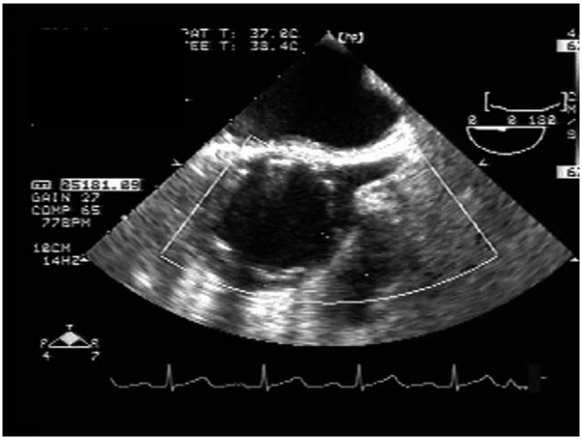

Fig. 4. Proof of patency of left main coronary artery after stent placement.

Recently, less invasive techniques (including the use of stent grafts) have been introduced. Short-term outcome has improved considerably, with a lower morbidity, mortality, and cost compared with the open surgical approach [52]. The long-term outcome is not yet known.

The anesthetic technique should be aimed at hemodynamic stability and early tracheal extubation. These patients have the same comorbidities as other vascular disease patients such as hypertension, coronary artery disease, COPD, and renal impairment. A balanced technique with the use of moderate doses of opioids and an inhalation agent is the most appropriate approach. The use of cisatracurium can assist in achieving this goal because many patients will have had multiple contrast injections with impairment of renal function. The use of nitrous oxide should be avoided because of the risk of air embolism [48]. Intubation and mechanical ventilation are indicated because, among others, TEE is an important monitor for the optimal placement of the endovascular stents [53]. An additional challenge for the anesthesiologist is the environment (if these techniques are performed in the radiology unit, which has extensive equipment and restricted movement space).

Acute peripheral occlusion and thrombosis

In cases of acute occlusion of peripheral arteries by an embolus or thrombosis, emergency surgery is indicated. A cold, painful foot, lack of pulse, and (often) paralysis are the most common symptoms. The surgical outcome is often poor [54].

There are a few options for the type of anesthesia. General anesthesia is often used with rapid sequence induction and mechanical ventilation. Most patients who have arterial thrombosis have a history of cardiovascular disease and COPD; the former complicates hemodynamic management and the latter might be better managed using spontaneous ventilation with a laryngeal mask airway technique. Alternately, monitored anesthesia care combined with local anesthesia can be used, particularly in less emergent circumstances, but reperfusion of an ischemic limb can lead to profound acid–base changes, which are difficult to treat.

Regional anesthesia is often contraindicated because the patient will receive anticoagulation with heparin. In the case of an amputation, heparin is terminated preoperatively, which facilitates the application of regional analgesia to improve the outcome of pain sensation.

Vascular trauma

If a patient has major vascular trauma, the conditions are determined mainly by the hemodynamic instability caused by blood loss. Unless other underlying comorbidities are present, the choice of anesthetics is aimed at stabilizing the patient's hemodynamics. Careful induction, sometimes merely including the use of ketamine, is indicated. Until the damaged blood vessels are clamped and the bleeding controlled, this anesthetic approach should be continued, adding a benzodiazepine when the patient is more stable.

Summary

The patient who undergoes major vascular surgery requires a well-chosen anesthetic technique. Perioperative myocardial and cerebral ischemia occur frequently, and particularly in emergencies such as dissections or acute occlusions, meticulously performed anesthesia is important for a favorable outcome. According to recent studies, the use of inhalation agents such as isoflurane and sevoflurane might be advisable because of their capacity to protect organs during ischemia because of the mechanism of preconditioning.

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