Cardiac Anesthesia and Postoperative Care in the 21st Century

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MOREMEDIA
Springer

Anaesthesia and Intensive Care for Adult Patients Undergoing Aortic Arch Surgery

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Introduction

Pathology of the aorta and major vessels is easily diagnosed in the 21 century. Symptoms are now better diagnosed by most healthcare professionals, and imaging is readily available. With the advent of good quality ultrasound devices enlarged and dissected vessels can be diagnosed at bedside, and computerised tomography and magnetic resonance imaging are available in most institutions, as well as the quality of the images is constantly improving. Patients need aortic arch surgery in all its permutations due to 3 reasons: Acute or chronically dissected wall; Enlarged aorta and its branches at a risk of dissection in the future; Re-operation to corrected earlier aortic surgical complications. Surgery for these conditions has evolved since its first description in 1956. However, it still involves cardiopulmonary bypass (CPB) with all its problems.

Despite many minimally invasive techniques (mostly stenting) having been developed as alternative to major, and undisputedly, very high-risk surgery (mortality 16–20%), replacement of the diseased vessels is still the main stay of treatment in 2019. The majority of the operations involve the replacement of the arch and branches with a multi-chimneys vascular graft, in which the distal portion seats in the descending aorta (elephant trunk); or to replace the arch with a multi-branch hybrid prosthesis, where the arch segment is a multi-chimneys conventional graft, but the distal segment is a stent graft (FET-frozen elephant trunk).

Discussions about aortic vessel disease mechanisms and its prognostication are beyond the scope of this chapter. However, when surgery is indicated the team

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M. Vives and A. Hernandez (eds.), *Cardiac Anesthesia and Postoperative Care in the 21st Century*, https://doi.org/10.1007/978-3-030-79721-8_18

needs to have detailed understanding of the procedure in all its phases. No other type of surgery requires closer team-working than this. Team-work in these cases defines survival, and more importantly the morbidity associated with it. Anaesthetists in these teams need to be involved in the decision- making and planning for surgery, intra-operative monitoring and bypass, coagulation management, and postoperative monitoring and care. Understanding of the exact pathology, and pre-morbid blood flow distribution are essential for the anaesthetist.

Pre-anaesthetic Assessment

In the case of *acute aortic syndromes* (type A dissection (Fig. 1) and aortic ulcers/ruptures) the pre-assessment is very easy. The patient needs an operation as a matter of urgency. The mortality is increased every hour of delay. If the patient is deemed suitable for surgery (absence of incurable malignancy, advanced frailty), then expediting surgery and haemodynamic monitoring and management take priority over details of pre-operative fasting, family history, etc. It is important that the patients and family have appropriate consent. The focus in such cases is on safe transfer to a cardiac centre; minimal safe blood pressure; management of pericardial collections; extent of dissection; blood transfusion requirements; plan for which vessels would be cannulated. Any pre-existing neurological deficit must be documented. The cerebral perfusion may have been impaired for a period of time, leading to increased risk of neurological deficit.

Elective aortic arch surgery patients have time for thorough assessment. This involves multidisciplinary approach with physicians, imaging specialists, surgeons, anaesthesiologists, perfusionists, and intensive care specialists. Individualised patient anatomy mandates individualised surgical plan. Choice of an aortic graft is

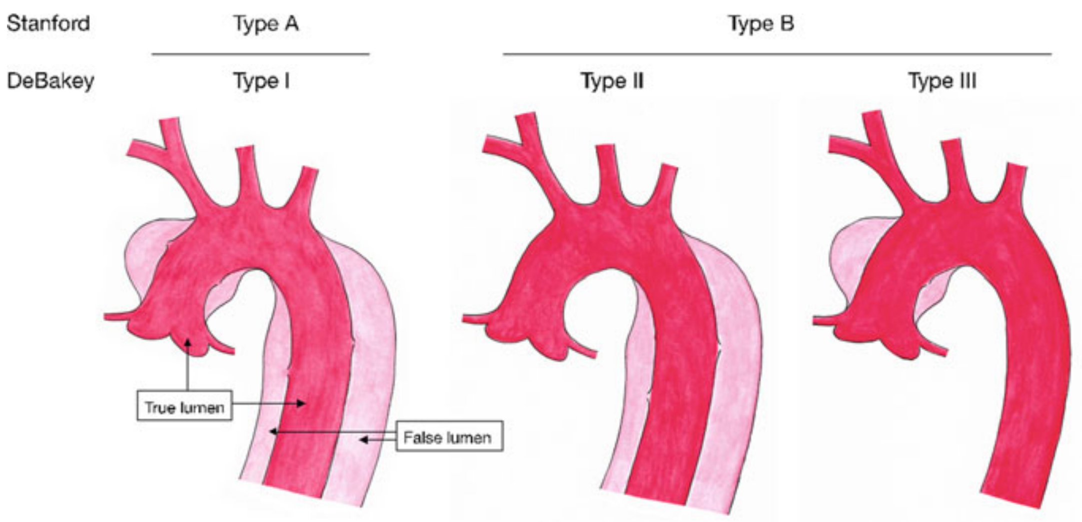

Fig. 1 Dissection types

important and the benefits weighed carefully. As part of the surgery includes cooling to reduce oxygen demand of different organs in times of diminished circulation the temperature planning and monitoring is important. Blood conservations strategies are discussed and the laboratory support enlisted. Cerebral and spinal cord protection is planned. Detailed anaesthetic assessment has to address any airway problems, cannulation of venous and arterial tree, drug and related medical history, and allergies. Finally, after a decision for surgery the patient needs to be presented with the potential benefits of surgery, vs potential complications.

Intraoperative Anaesthetic Management

Full understanding of the surgical plan is paramount to establish the appropriate invasive monitoring and plan for the best possible organ protection. As the nature of replacing the arch is associated with a high risk of brain, spinal cord and heart injury, the anaesthetic and perfusion strategy has to be tailored to prevent organ damage.

Anaesthetic induction: Although it is good practice to have an invasive arterial line monitoring before anaesthetic induction, these vascular patients are overall low risk from the heart performance point of view. The majority have good left ventricular function with some degree of aortic regurgitation that is frequently well tolerated. The 'Re-do' cases, previous Type A repair patients (about 3–11% of arch replacement) could be considered the high-risk group, as they may suffer biventricular dysfunction as a result of compromised coronary perfusion during the first emergency surgery. The selection of volatile or intravenous agent for induction and maintenance has no influence in outcomes; however, the use of high dose of opioids may be associated with higher risk of spinal cord injury. Airway can be secured with a single lumen endotracheal tube. Vascular and tracheobronchial compression as a result of a large aneurysm is rare but it can cause airway obstruction, bleeding and trachea-bronchomalacia.

Monitoring

A central venous catheter is useful for preload monitoring and inotropic support, and it can also be guidance on cerebral drainage, which can be mechanically compromised with clamps and tissue displacement. The innominate vein may need to be divided to dissect a large arch aneurysm or accidentally injured during dissection in re-do cases. Preference is therefore given to the central venous catheter in the right internal jugular, as well as the large-bore cannula for volume resuscitation. Pulmonary artery catheter may be necessary for Re-do cases, where up to 39% of patients have some degree of ventricular dilation or left ventricle dysfunction. Cardiac output monitoring and inotropic support becomes more relevant after the operation, to improve cardiac performance and ensure distal organ perfusion, which can be compromised once the false lumen in the descending aorta becomes excluded (thrombosed) and the remaining rudimentary vascular bed takes over. Echocardiography is essential in the operating theatres for assessment of ventricular function.

Since the ascending aorta and aortic arch are diseased, and they have to be resected for the operation, the CPB arterial cannulation is often peripheral (right axillary, carotid or femoral artery (Fig. 2)), which makes the brain, heart and other organs perfusion retrograde to the arch and ascending aorta. These patients often

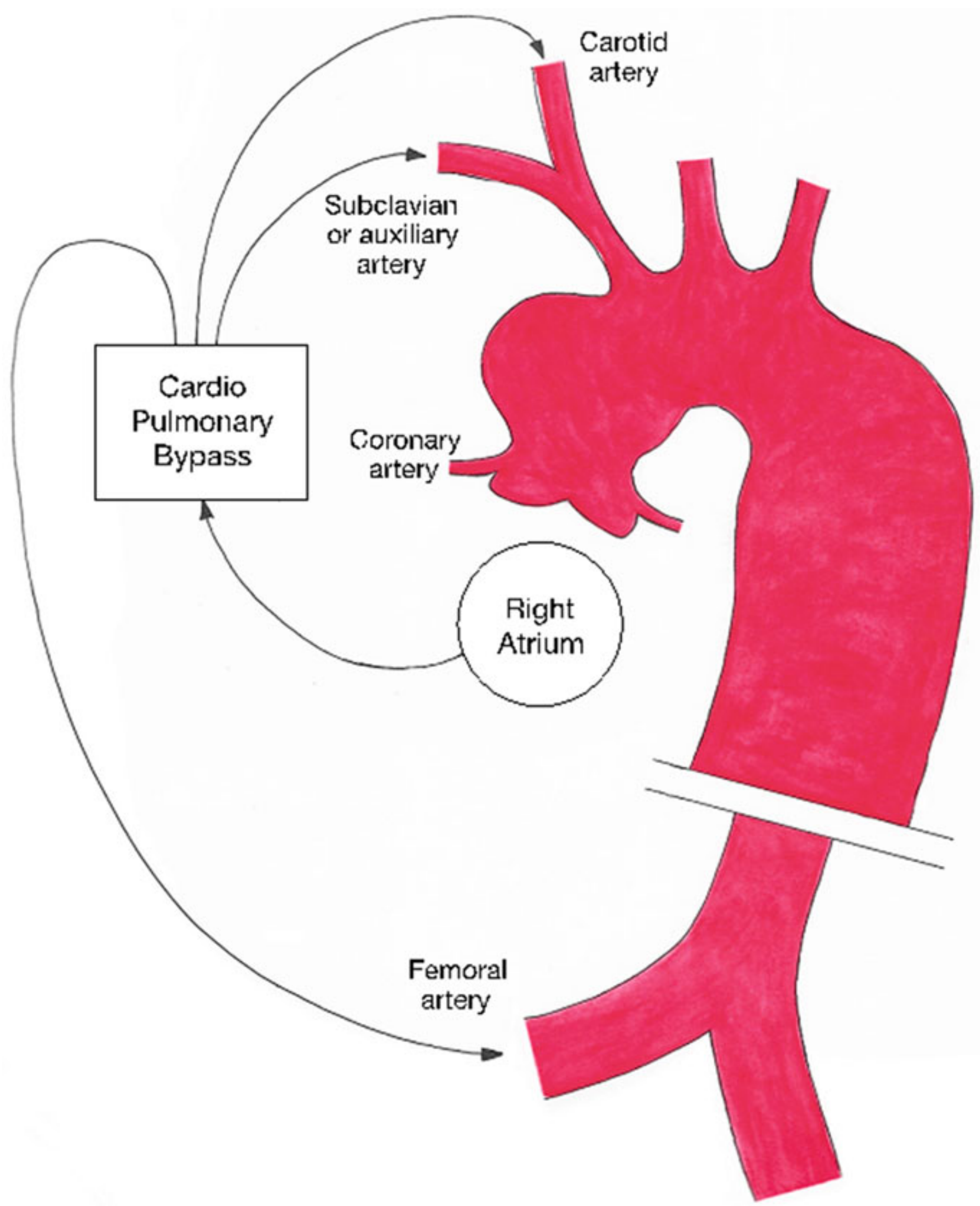

Fig. 2 Bypass cannulation options

have dissected peripheral vessels with flaps or thrombosis at different levels such as innominate artery (10–15% of cases), carotid, or femoral artery, particularly patients who underwent previous type A dissection repair. To ensure effective CPB flow to the arch and descending aorta, the invasive arterial monitoring can be placed in two distant points from the arch such right radial and a femoral artery.

Near infrared spectroscopy (NIRS) can be used to assess cerebral haemoglobin oxygenation. In general terms, cerebral oxymetry values that remain in line with pre-bypass readings, could be considered a good marker of adequate carotid perfusion but the evidence to support this statement is still lacking. Since the NIRS sensors are placed on the forehead, their trends are a good reflection of frontal lobes perfusion. However, it is not clear that using NIRS can influence neurological outcomes after aortic arch replacement. Considering that some patients have an anatomical variance of the circle of Willis, and a posterior communicating vessel is absent in 35% of patients, cerebral NIRS neither guarantee blood supply to the posterior part of the brain, nor offers a reliable guidance on global cerebral perfusion. Despite its limitations, an acute drop in the near-infrared spectroscopy value is highly sensitive to detect mechanical impairment to blood flow, such as cannula malposition, vessel dissection or flow steel into an open vessel.

Perioperative Transoesophageal echo (TEE) is a useful tool for multiple key points during surgery: Assess baseline cardiac function; Grade the aortic regurgitation; Confirm that the aortic arch prosthesis is well-expanded in the descending aorta; Assess cardiac function after the operation. In patients who undergo root replacement, problems with the coronary re-implantation may trigger regional wall motion abnormalities that can be identified and located with TEE guidance. The use of retrograde femoral perfusion can lead to descending aortic rupture or false lumen expansion, and it could be identified with TEE during the operation. When the surgical technique involves continuous antegrade coronary perfusion (400–700 mL warm blood given to the heart through a cardioplegia cannula) the use of TEE is essential to detect LV distension due to poor ventricular venting or aortic regurgitation (i.e. mild aortic regurgitation or washing jet of mechanical valves in previous type A).

Temperature monitoring in at least two territories is important to ensure that the target temperature has been achieved. If the arterial CPB cannulation is close to cerebral vessels (i.e. right axillary), the use of a nasopharyngeal probe as a sole source of temperature can lead to overestimation of hypothermia. Distal organs such as kidneys and spinal cord can remain warm and at risk of ischemic injury during the circulatory arrest. The use of selective cerebral perfusion (SCP) during circulatory arrest can only contribute to the upper spinal cord perfusion up to T3–T5, but not in segments below that level. Therefore, ensuring that the target temperature has been achieved in the lower body is a corner stone in minimising the risk of spinal cord injury. The use of bladder or rectal temperature probe appears to be a good surrogate of spinal cord temperature. In contrast, when return cannulation is placed in the femoral artery, the temperature measured in the upper body (such as esophagus) tends to be higher than that measured in the lower body. A ten degrees gap between blood and nasopharyngeal temperature favours a slow cooling to ensure all regions are cold before circulatory arrest. Rewarming should be preceded by a 5-min interval of cold reperfusion, which has been associated with improved cognitive recovery in experimental studies.

Perfusion

For cases undergoing circulatory arrest with selective cerebral perfusion, more than two or three isolated regional perfusion circuits are running at one particular time to deliver regional blood supply to the brain, the heart and the lower body. Perfusion for deep hypothermic (18–20°) circulatory arrest requires discontinuing circulation for an interval to facilitate the distal anastomosis completion. In that scenario a dynamic and close collaboration between perfusionist, anaesthetist and surgeon is essential.

During the lower body hypothermic circulatory arrest, the two circuits running may include: a cold SCP that is diverted from the arterial line (clamp on the innominate artery) and a second warm circuit to the heart (regional heart perfusion). It is good practice to split the lines at a pump level, rather than on the field, to be able to measure accurately the resistance and amount of flow to any particular area. Once the HCA is finished, a third cold circuit will be added to perfuse the lower body through the graft into the descending aorta.

Spinal Cord Protection

Patients undergoing elective aortic arch replacement may present with a large aneurysm and an intact descending aorta; A previous Type A repair with a chronically dissected descending aorta; or A type B dissection that requires arch replacement to stent the descending aorta in a later stage. The last two types are at higher risk of spinal cord injury. The collateral network of the spinal cord is very complex, and its vascular interconnection between the thoracic, the lumbar spinal plexus and the vertebral circulation play a major role in prevention and treatment of perioperative paraplegia. Although the lower body hypothermic arrest is inevitable, and usually short enough to preserve the spinal cord, it does inflict a degree of sub-lethal ischemia that leaves the spinal cord vulnerable after surgery. The duration of the arrest, the temperature, and the number of segments of thoracic aorta occluded with the stent will impact in neurological outcomes. Delayed perioperative paraplegia is the commonest presentation. In addition to intraoperative sub-lethal ischemia in theatres, the spinal cord swelling, lack of collateral network (i.e. occluded left subclavian), or systemic hypotension can precipitate a delayed spinal shock that if not treated promptly can be permanent. Maintaining high perfusion pressure after the haemostasis has been achieved is paramount. The use of inotropes and vasoconstrictors to achieve mean arterial pressure of 100–120 mm

Hg is often required in symptomatic patients. The insertion of a spinal catheter for cerebrospinal fluid drainage can be beneficial to augment spinal perfusion. High perfusion pressure and spinal drainage will be required for a period of time post-operatively. It appears that between 48 and 96 h after segmental arteries occlusion, a neo-vascular genesis can restore the flow through a dramatic increase in the paraspinal vascular bed, thus the risk of delayed paraplegia is progressively reduced.

Surgical Techniques: (Fig. 3)

Type of surgery is determined by the site of pathology. Surgery for type A aortic dissection aims to restore stability of the integrity of the ascending aortic wall. If the aorta is dissected there must be an intimal tear. The tear has a propensity to expand and the danger is that it may compromise coronary circulation, produce overwhelming aortic valve regurgitation, or tear into the pericardium producing tamponade and death. To avoid these rapid and life threatening complications the ascending aorta needs to be replaced as a matter of urgency.

The aims arch surgery are to resect the primary intimal tear and seal tears extending beyond the transverse aortic arch, as well as to cause false lumen obliteration of the descending thoracic aorta.

Arch replacement: Historically, the classic elephant trunk technique was developed by Borst in 1983. It involves replacement of the ascending aorta and aortic arch with the 3 major branches, not extending to the descending aorta.

Hemiarch: Hemiarch surgery is usually performed in patients who undergo aortic root replacement and present with a distal aorta or proximal arch aneurysm.

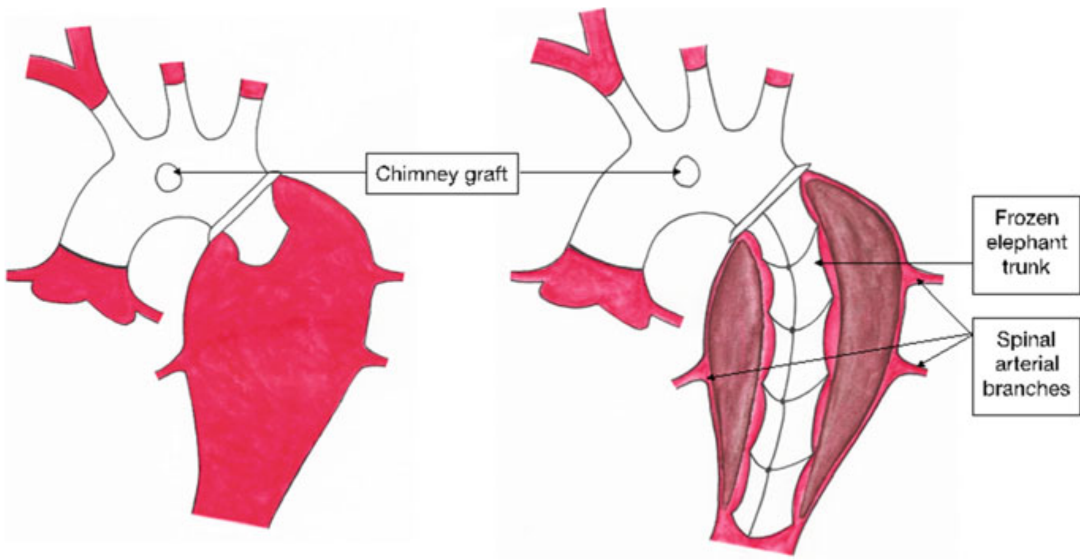

Fig. 3 Conventional elephant trunk (Left) and Frozen Elephant Trunk (Right)

This procedure is similar to interposition graft where ascending aorta is replaced as well as the inferior part of the aortic arch. However, the superior part of the arch where the head vessels are is left uninterrupted. There is a trend to perform hemiarch surgery for type A dissection or elective aortic root replacement when the arch is only mildly dilated, however, it is not clear if that would prevent patients from developing further arch aneurysm. There is controversy around the benefits outweighing the extra risk associated to deep hypothermic arrest and perioperative complications such as stroke, spinal cord injury and bleeding. However, numerous series publications have shown that the mortality and morbidity doesn't differ from isolated aortic root replacement.

Frozen elephant trunk: To overcome the limitations of conventional elephant trunk, a concomitant stented graft was developed and incorporated as an adjunct in the descending aorta, the frozen elephant trunk (FET) procedure. The FET technique has involves antegrade deployment of the descending aortic stent graft through the open arch during hypothermic circulatory arrest. The concerns with this procedure are that the descending aortic graft produces thrombosis of the highest part and can occlude flow in branches, which feed superior part of the spinal cord. The largest international registry including more than 11,000 patients did not show the outcomes of this procedure for Type A dissections to be worse than conventional elephant trunk.

Risks

Bleeding: Bleeding is the commonest complication of aortic surgery. As with any cardiac surgical bleeding the magnitude it is mostly dependent on extravasation from suture lines. The surgical technique and quality of tissues are the most important factor. The anaesthetist in these cases has also major role. Good teamwork with surgeon, perfusionist and blood bank cannot be overestimated. The blood loss in these cases can be very rapid and preparation and experience is very useful.

Correcting coagulopathy associated with long bypass and hypothermia are paramount. It has to be born in mind that prompt correction of coagulopathy with protamine and blood product allows the surgeon to see the bleeding spots that need suturing and allows for prompt haemostasis.

Hypertension during initial haemostasis is undesirable. The role of the anaesthetist is to control the blood pressure to lowest safe level, allowing haemostasis while maintaining perfusion to vital organs. While it is not known what is safe lowest blood pressure, and it varies from patient to patient, mean arterial pressure as low as 50 mm Hg can be tolerated by most patients for a short period of time.

Use of anti-fibrinolytics has been debated over time. High dose tranexamic acid and aprotinin have both been advocated. It has to be appreciated that although the use of aprotinin is associated with acute renal failure, these are high-risk operations and sometimes the risk of this complication is justified by the benefit of avoiding severe coagulopathy.

Myocardial dysfunction: Meticulous intraoperative myocardial protection by the surgeon is paramount for all major cases. The role of anaesthesia in this setting is no other than ensuring that myocardium has been perfused where appropriate, as indicated by ECG changes. In cases when myocardial injury has occurred the choice of post-operative inotropic agents as guided by invasive monitoring, TEE, and cardiac output is important.

Stroke: The second most devastating complication after paraplegia in aortic arch surgery is stroke. While in the general cardiac surgical population the common reason for stroke is embolic, in the aortic surgical patients this is ischaemia related to malperfusion of a carotid artery for a length of time. The incidence of 10% makes this a very frequent complication, and the patient must be warned about it. Ensuring intraoperative perfusion of all of the brain is essential, and use of cerebral oxymetry has been recommended, yet of no proven benefit.

Respiratory failure: It is difficult to define isolated respiratory failure in the post-operative setting in these patients. Hypoxia and hypercarbia are not frequent problems in uncomplicated cases. However, the risk factors are: poor premorbid condition, emergency surgery, prolonged bypass, blood products administration. If this occurs, it has a major impact on the weaning form mechanical ventilation and assessment of neurology. In cases where prolonged mechanical ventilation is required the use of alpha-1 agonists like dexmedetomidine to allow arousal and neurological assessment have been recommended.

Renal failure: It is important to remember that incidence of pre-existing renal impairment in this category of patients is common, and also the duration of cardiopulmonary bypass longer than other operations. It is therefore not surprising that the incidence of acute post-operative renal failure is as high as 21%. No renal protection strategy has been of proven benefit for cardiac surgical patients, and optimal renal perfusion intraoperatively is the best strategy. If the acute renal injury is diagnosed post-operatively the treatment is supportive, via renal replacement therapy. If sure to a dissected segment of the aorta both renal arteries have impaired perfusion then permanent renal failure is likely. The influence of hypothermia on renal protection has also been questioned, and it seems that deep or moderate hypothermia offer the same protection.

Complication rate in this group of patients is not inconsiderable. Many studies have presented data, and probably the most consistent is from the Martens publication in 2016: stroke 10%, dialysis 21%, spinal cord injury 5%.

ICU Management

Wake up versus asleep: All patients undergoing aortic arch surgery are postoperatively cared for in an intensive care environment. Once surgery is completed the patient is transferred sedated and mechanically ventilated to the intensive care unit. Immediate or earliest arousal for assessment of neurological function is always the best approach. Early awakening may not be practical for the following reasons:

need for meticulous blood pressure control; bleeding and need for chest re-exploration; and respiratory failure. It has to be remembered that despite advanced monitoring of brain and spinal cord perfusion, the best way to assess these functions is to wake up the patient and ensure arousal and adequate motor function. If sedation has to be continued there is a risk of delayed diagnosis of spinal malperfusion, delayed treatment, and permanent neurological deficit.

Bleeding and open chest: Bleeding is not uncommon in aortic surgery. The goal of good intensive care management is tight blood pressure control and correction of coagulopathy. Proactive management of both is essential. In rare cases massive blood loss and technically challenging operations can lead to swelling of the intrathoracic organs. In such cases the chest cannot be closed, and patients may need to be left with unopposed sternum for several days. Infection control in such cases is important as risk of mediastinitis is high.

Spinal cord monitoring: Replacement of descending aorta mandates spinal cord monitoring intraoperatively, and some form of post-operative monitor. Patients undergoing aortic arch surgery seldom have their regional spinal perfusion interrupted. However, on rare occasions when the patient wakes up with signs of paraplegia aggressive optimisation of spinal perfusion is essential to avoid permanent damage. Spinal drainage and optimising spinal perfusion pressure (i.e. high mean arterial pressure) in the post-operative period are the main stay of treatment.

Pain and delirium management: Postoperative Delirium is common in acute aortic dissection patients (34%). The risk factors include cerebrovascular disease history, surgery and cardiopulmonary bypass duration, postoperative hypoxia. Recognising risk factors early and managing delirium could contribute to early recovery, and avoiding complications associated with prolonged ICU stay. Analgesia is seldom a problem for sternotomy patients and simple morphine infusions or boluses are conventionally used. However, patients who need thoracotomy for surgical access (unusual for aortic arch surgery) may need regional analgesia in a form of epidural and paravertebral blocks.

Gold standards of good intensive care management also include careful Infection vigilance; Mobilisation and nutrition; and Early rehabilitation and discharge planning. Finally, all aortic and cardiac surgical centres maintain rigorous analysis of performance via audit and reporting of results. This ensures high healthcare standards, and best results for patients. Litigation for unexpected mortality or neurological injury in this category of patients is not uncommon, and solid medico-legal defensive practice is helpful in such cases.

Recommended Readings

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