Neuroprotective Strategies for Spinal Cord during TEVAR

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Thoraco-abdominal aortic repair is a high-risk surgery for both mortality and morbidity, thoracic endovascular aortic repair (TEVAR) is a minimally invasive option for the management of the pathology of the descending thoracic aorta compared to open surgical repair (OPEN). A major complication is paraplegia-paralysis due to spinal cord injury. Modern thoracic and abdominal aortic aneurysm repair techniques involve multiple strategies to reduce the risk of spinal cord ischemia during and after surgery. These include both surgical and anaesthesiologic approaches to optimize spinal cord perfusion by staging the procedure, guaranteeing perfusion of the distal aorta through various techniques (left atrium–left femoral artery by-pass) by pharmacological and monitoring interventions or by maximizing oxygen delivery and inducing spinal cord hypothermia.

aortic repair | aneurysm | vascular surgery | neuroprotection

1. Surgical Strategies

In cases where an extensive coverage of the aorta is planned (e.g., >30 cm), a two-stage procedure can be considered to reduce risk of spinal cord ischemia (SCI) [1]. A two-stage approach includes firstly implanting a thoracic proximal endograft above emerging vessels. After two to three months, a distal stent will be placed [2]. Furthermore, surgical options to ensure flow to the left subclavian artery are revascularization or endovascular techniques are used. Revascularization procedures include the transposition of the subclavian on the left common carotid artery or insertion of a small bypass [3]. Endovascular techniques involve the use of fenestrated/branched stents, chimney and periscope graft, sandwich techniques, and fenestration techniques in situ [4]. Current guidelines [5] suggest previous revascularization of the left subclavian artery in patients undergoing thoracic endovascular aortic repair (TEVAR) if proximal stent seal covers the artery emergence. Selective revascularization is absolutely indicated in patients with coronary artery bypass grafted with internal mammary artery in the presence of an arteriovenous fistula on the left arm and in left-handed patients. Relative indications include dominance of the left vertebral artery, extensive aortic coverage, previous AAA repair, and occlusion of the hypogastric artery. Post-operative indications to revascularization concern upper limb ischemia or onset of vertebrobasilar insufficiency [6]. Minimally invasive segmental artery coil embolization (MISACE) is a novel technique preconditioning to ischemia, inducing neo-angiogenesis, and improving vascularization of spinal cord before TEVAR. Despite encouraging prospects, reproducibility of this technique in patients with tortuous vessels or with thrombi localized in the aneurysm sac is not easy [7], and there are also concerns because the procedure itself can cause SCI. Temporary aneurysm sac perfusion (TASP) is a technique involving a two-stage procedure: the first step consists of the creation of an endoleak in the lateral branch of the endoprosthesis which perfuses the main splanchnic vessels, and one to three months later, a stent deployment will close the endoleak [8]. The use of branched or fenestrated stents is associated with a lower risk of the onset of SCI [9].

2. Anaesthesiologic Strategies

The anaesthetic approach to perioperative management of thoracic aortic aneurysms repair is fundamental and contributes to the prevention and management of complications. A goal-directed hemodynamic strategy is mandatory to achieve adequate spinal cord oxygenation and perfusion by a correct and adequate management of cardiac index (>2.5 L/min/m^2) and serum hemoglobinemia concentration [10]. As stated before, spinal cord perfusion pressure is the difference between mean arterial pressure (MAP) and cerebrospinal fluid (CSF) pressure [11]. Optimizing systemic arterial blood pressure (MAP > 90 mmHg) and CSF pressure (<10 mmHg) allows to achieve an adequate spinal cord perfusion pressure (>80 mmHg) [12]. Data reported in literature [10] demonstrates that maintenance of spinal cord perfusion pressure >80 mmHg through MAP increase and CSF drainage after placement of the aortic stent can prevent and reverse SCI and paralysis. In patients developing postoperative ischaemia, MAP > 90 mmHg should be the first step of treatment (vasoactive drugs). Vasopressors should be gradually reduced over the next 24–48 h after the improvement of symptoms [13]. Neurophysiological monitoring is useful to detect spinal cord ischemia during both open and endovascular surgery [12][14]. Motor evoked potentials (MEPs) can evaluate descending spinal pathways, while somatosensory evoked potentials (SSEP) are used for ascending pathways. One limitation to their application is the inability to differentiate medium from severe SCI. They are also affected by lower limb ischemia caused by vascular introducers [15]. Furthermore, volatile anaesthetics alter cortical waves, increasing latency and reducing the amplitude of SSEP; then, they should be administered at no more than 0.5 MAC [16][17]. For these reasons, intravenous anaesthesia is recommended when evoked potentials are monitored (e.g., propofol and remifentanil infusions and, if necessary, low concentrations of volatile anaesthetic) [18]. Administration of neuromuscular blockers must also be carefully monitored to ensure muscle relaxation and an adequate MEP response. Near infrared spectroscopy (NIRS) is another useful monitoring used during TEVAR for diagnosis of SCI. Electrodes are placed on the surface of paraspinous muscles at the thoracic and lumbar level. NIRS provides measurement of blood oxygen saturation in paraspinous circulations, close to spinal cord microcirculation, reflecting indirectly its oxygenation and blood perfusion [19]. However, this promising technique has yet to be clinically validated [20], and its routinary use is not yet recommended [21]. Moderate hypothermia (32–35 °C) may play a role in spinal cord neuroprotection [22]. Hypothermia may be used to provide some degree of acute tolerance of spinal cord to perfusion disruption during surgery, especially open surgical repair (OPEN). It can be achieved systemically through cardiopulmonary bypass or by infusion of cold fluids into epidural space [21]. However, systemic hypothermia is associated with several risks, such as dysrhythmias, coagulopathy, and metabolic alterations, while selective spinal cord hypothermia through epidural cooling is an invasive procedure, applicable for a limited duration with high risk of contamination and spinal cord rebound oedema [23]. However, this practice is poorly used in TEVAR as it requires a very invasive approach compared to the procedure which is minimally invasive [24], and in vitro studies showed hypothermia can alter the structure of grafts, causing deformation, migration, and endoleak [25]. The pharmacological protective strategy can also reduce spinal cord metabolic demands and inflammatory-neurochemical response to ischemia and reperfusion, especially when combined with other preventive strategies, such as CSF drainage. High dose of methylprednisolone (30 mg/kg) before aortic clamping [26] or intrathecal papaverine to improve spinal cord perfusion [27] or naloxone infused at a rate of 1 mcg/kg/h, starting before induction up to 48 h after surgery [28], are the most adopted strategies. SCI-induced neuronal cell death is triggered by the presence of redundant excitatory neurotransmitters, especially glutamate, glycerine, and aspartate that cause an excessive influx of calcium [29]. In experimental settings, naloxone reduces CSF glutamate and aspartate concentrations but not glycerine [30]. However, today there are no definite recommendations on routine use of these drugs to avoid SCI. CSF drainage is the most effective procedure in preventing SCI after aortic repair because acute changes due to ischemia and reperfusion result in spinal cord oedema and increased CSF pressure and finally spine cord perfusion pressure (SCPP) reduces. Current guidelines [14] recommend CSF drainage for both open and endovascular thoracic aortic aneurysm (TAA) repair in patients at high risk of SCI. Specific indications to CSF drainage in patient undergoing TEVAR were recently identified, although further validation needs [31].

Postoperative CSF drainage is indicated in patients with delayed paralysis following TEVAR within two hours of symptom onset. Although recent works [10] do not recommend this practice since the mechanisms of delayed paraplegia are not fully understood yet, CSF drainage can be performed on the day before surgery to recognize early any sort of complications [32] or can be scheduled on the day of surgery [20]. In any case, the timing of CSF drain placement does not have an impact on the post-discharge functional impairment or long-term mortality [33]. Hemodynamic optimization plus CSF drainage is currently recommended as the best strategy to avoid or reduce risks of SCI during TEVAR [20]. For this purpose, a silicon drainage catheter is inserted approximately 8–10 cm into the subarachnoid space at the lumbar level, allowing measurement of CSF pressure and CSF drainage [34]. Current recommendations [1][2][3][4][5][6][7][8][9][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][32][33][34][35][36][37] suggest continuous monitoring of CSF pressure to monitor the ICP wave and prevent catheter obstruction. Intermittent rather than continuous CSF drainage reduce the risks of the development subarachnoid haemorrhage due to excessive loss of CSF in a short time [38][39][40]. The rate of complications after lumbar drainage placement is 0.3–1.0% [41]. The most frequent is localized infection (11.1%), post-dural puncture headache (3.3%), puncture site bleeding (2.1%), persistent CSF loss (1.3%), subdural hematoma with no clinical evidence, abducens nerve palsy, catheter displacement-occlusion (0.1%), or fracture (0.15%). More severe complications are meningitis (0.1%), subdural hematoma (1.7%), and intracranial haemorrhage (1.8%) [42]. The latter may be associated with excessive CSF drainage stretching and tearing of the dural veins. To minimize the risks of subdural hematoma, a CSF pressure ≥10 mmHg is recommended in the absence of ischaemia or to perform an intermittent drainage of 10–20 mL/h with continuous blood pressure monitoring. Patients with cerebral atrophy, arteriovenous malformations, brain aneurysms, and history of previous subdural hematoma are particularly disposed to develop cerebral haemorrhage [39]. Normal haemostatic panel and platelet count is also recommended before the procedure and withdrawal time of any anticoagulant and antiaggregant drugs must be properly respected [43]. The catheter should be kept in place for at least three days. In fact, delayed paralysis occurs after 1.8 days and is frequently associated with hypotension or catheter malfunction. CSF aspiration of 10–20 mL/h is recommended if intracranial pressure (PIC) > 10 mmHg, while fluid or vasopressor infusion can support the hemodynamics [44].

Type of Anaesthesia

General anaesthesia is mandatory for open thoracic aortic surgery, and it is often performed for TEVAR. This allows a safe control of the airways in case of haemorrhagic shock or rapid conversion to open surgery, the possibility for intraoperative monitoring with trans-esophageal echocardiography, avoids involuntary movements of the surgical field related to the patient's respiratory pattern, and ensures the pacemaker's heart rate control. Nevertheless, neuraxial and locoregional anaesthesia are emerging techniques in TEVAR [45]. Neuraxial anaesthesia can provide adequate pain relief on large bore of vascular access sites and relieve discomfort related to the prolonged fixed position. Moreover, it allows continuous monitoring of clinical signs of cerebral ischemia. On the other hands, spinal anaesthesia is associated with haemodynamic instability and with the risk of spinal hematoma. Local anaesthetic infiltration of femoral access sites, combined with slight sedation (also known as monitored anaesthesia care), is an alternative technique preserving patient's consciousness and ability to obey orders without pain and haemodynamic stability and finally allowing to directly monitor the spinal cord function. In these cases, patient cooperation is crucial as spontaneous movements are possible during critical surgical manoeuvres, and pain and stress are less manageable. Currently, there are insufficient scientific data to recommend any of these techniques as a first choice in the management of TEVAR; still evidences in endovascular abdominal aneurysm repair (EVAR) show less postoperative pulmonary complications [46], shorter in-hospital length of stay, and lower mortality [47] in patients undergoing regional/local anaesthesia.

3. Special Consideration for Aortic Dissection Repair

Aortic dissection is a life-threatening condition caused by tears of the aortic inner layer through which blood enters and flows. The resulting false lumen can lead to occlusion of aortic branches and consequent ischemia. The Stanford classification divides aortic dissections into type-A with involvement of the ascending aorta and type-B, originating distal to the left subclavian artery. Emergency surgery is mandatory for treatment of type-A dissections. Total arch replacement is obtained by a Dacron prosthesis (frozen elephant trunk) that provides an anchoring platform for following distal endograft.

Spinal cord injury is a well-known complication following this procedure (8.9%) [48].

Risk factors associated with SCI are stent extent greater than 15 cm, a coverage at or distal to T8, and length of circulation arrest [49]. Ensuring blood flow to the left subclavian and femoral artery via extracorporeal circulation during circulation arrest and guaranteeing hypothermia are techniques used to prevent SCI during aortic arch repair [50]. Intraoperative CSF drainage is not currently recommended due to emergency surgery, but it can be useful postoperatively to treat sudden paraplegia, according to data of aortic aneurysm repair [51]. Not-complicated type-B dissection requires a first step conservative treatment with medical therapy and rest. Then, endovascular surgery can be planned. Urgent TEVAR is indicated in the type-B dissection presenting with persistent pain, uncontrolled hypertension, early aortic expansion, signs of malperfusion, or rupture [52]. In all these cases, recommendations similar to those postulated for aneurysm repair can be applied for the prevention of SCI.

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