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Thoracoabdominal Aortic Surgery With Special Reference to Spinal Cord Protection and Perfusion Techniques

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Introduction

Despite many protective measures during and after surgery, the morbidity and mortality of thoracoabdominal aortic aneurysm (TAAA) repair remains a major concern. Spinal cord ischaemia and renal failure are the main complications besides myocardial infarction, multiple organ failure, visceral ischaemia and pulmonary problems. The first Nordic workshop of TAAAs was organised in 1992 and it was then generally agreed that the surgical method of choice was the Crawford technique with direct cross-clamping.[1] During the last 5 years, however, different techniques have been developed and the aim of the second workshop was to evaluate progress in experimental and clinical research and to discuss the potential benefits for the patient.

Spinal Cord Ischaemia and Protection

In the workshop it was confirmed that the most extensive aneurysm (type II) carries the highest risk of paraplegia and mortality.[2] Spinal cord injury is largely due to the duration of ischaemia and failure to re-establish blood flow after aortic repair. The mechanism of delayed paraplegia is not completely understood but is associated with raised cerebrospinal fluid (CSF) pressure, intra- and postoperative hypotensive periods or occluded reattached intercostal arteries.

To combat spinal cord ischaemia, the importance of the intercostal blood supply from T6 to L1 was stressed. Animal models and the use of laser Doppler fluxmetry show reduced spinal cord perfusion following cross-clamping of the descending thoracic aorta or the azygos vein. Drainage of spinal fluid during cross-clamping increases microcirculatory perfusion of the spinal cord.[3] These experimental results were clinically confirmed by combining cerebrospinal fluid drainage and distal aortic perfusion, significantly reducing neurologic complications after repair of TAAA types I and II.[4,5] Thus, CSF drainage is now regarded as an important adjunct. There was no dissent from the requirement for continuous CSF drainage to maintain a pressure of less than 10 mmHg. There was agreement that a CSF pressure exceeding 30 mmHg was associated with paraplegia. Nevertheless, it was recognised that CSF drainage alone does not prevent all ischaemic events of the spinal cord.

Although a short clamp time is of importance the majority of participants were against the rapid no heparin "clamp and go" method, in favour of distal aortic perfusion, low dose heparin (1 mg/kg) and careful intercostal artery incorporation. Local cooling of the spinal cord[6] or systemically by extracorporeal circulation[7] was seen to increase the ischaemic tolerance.

Participants felt that detection of spinal cord ischaemia during surgery would be a great advantage so that measures to re-establish blood supply to the spinal cord could be improved. It was generally agreed that somatosensory evoked potentials (SSEP) are inaccurate because they do not reflect motor function. Several techniques for monitoring motor neuron pathways exist, but only myogenic responses are entirely specific for the status of the motor neurons in the anterior horn. Transcranial motor-evoked potentials (MEP) were used in one centre and were demonstrated to be important in monitoring spinal cord function. Spinal cord ischaemia could be detected within minutes and the technique helped to identify segmental arteries

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that needed reattachment.[8,9] Furthermore, monitoring MEPs allowed us to determine the necessary mean arterial pressure to maintain adequate spinal cord perfusion. This critical pressure can vary considerably between individuals and is important for the post-operative period to avoid delayed paraplegia. The minimal mean arterial blood pressure necessary to maintain adequate spinal cord perfusion in the post-operative period must be kept.

Distal Aortic and Selective Organ Perfusion

The main disadvantage of the "clamp and go" technique is the visceral and renal ischaemia. Prolonged ischaemia is the main cause of renal failure and can also contribute to multiple organ failure due to liver and bowel hypofusion. Neutrophil activation and endotoxinaemia are shown during TAAA surgery in type I, II, III and IV aneurysms.[10] Maintaining renal and visceral perfusion by means of retrograde aortic perfusion during cross-clamping diminishes ischaemic damage, provided that the pressure is high enough to adequately perfuse the organs. During the first part of the reconstruction this can be achieved by combining distal perfusion and sequential aortic cross-clamping. The use of left heart bypass with a centrifugal pump, however, did not reduce the incidence of renal complications in type II patients.[11,12] This might be explained because distal aortic perfusion is interrupted during reattachment of the visceral and renal arteries, which can be avoided by selective organ perfusion.[4] The evidence remains confusing since direct perfusion of the renal arteries with non-pulsatile blood flow had a deleterious effect in one study.[13] The reason for this may be an insufficient pressure at the tip of the perfusion catheter and therefore it was emphasised that it might be helpful to have a transducer at the distal site to monitor perfusion pressure and volume flow to the organs. Distal aortic and selective organ perfusion is a promising technique to prevent ischaemic renal and intestinal damage during cross-clamping.[14] However, one study found renal artery cold perfusion to produce equivalent results to any other method.[15] Distal aortic perfusion can be achieved by cannulation of the left atrium or pulmonary vein and the femoral artery using heparin-coated tubing systems, requiring minimal heparinisation. In the centres where this was used only a few bleeding complications were observed, in contrast to cardiopulmonary bypass where systemic heparinisation is necessary, leading to more extensive blood loss and lung haemorrhages.

Several techniques to establish organ perfusion are available. The coeliac trunk, superior mesenteric artery and both renal arteries can be selectively perfused with Pruitt-catheters which are connected to the extracorporal circulation. An alternative is perfusion through a side-arm of a 8-mm dacron graft which is pre-constructed before the cross-clamping. This system can be combined with distal aortic perfusion or not, but it was stressed that distal perfusion was favoured by anaesthesists to correct the effects of increased cardiac afterload following cross-clamping.

Besides these haemodynamic advantages, distal aortic perfusion allows gentle clamping, secure anastomoses without the need to hurry, reduced post-clamp acidosis, reduced risk of cerebral perfusion overload and reduced need for pharmacological intervention during clamping. Extracorporeal circulation, however, might induce complications like bleeding at the cannulation sites, embolisation and dissection of the aorta and visceral arteries. In general, it was agreed that the incidence of these complications is low and that the advantages outweigh the disadvantages. Therefore it is recommended to consider distal aortic perfusion in the protocol of TAAA repair especially for type II aneurysms. Over the 5-year period, the acceptance of the value of the left heart bypass with low dose heparin as described above shows a change in policy from the first workshop on this subject.

Pathophysiology and Anaesthesia

Cardiac function and cerebral blood flow

Provided one is using anaesthetic agents which do not depress the cardiac function, there is an increased cardiac output during cross-clamping of the thoracic aorta. This is seen both in animal experiments and in patients. During the first 5 min after cross-clamping, however, there is an increased afterload which then returns to normal after 10–20 min. The contractility is then increased above normal. During the initial 5 min, however, there is a slight decrease in cardiac output, heart rate and stroke volume, whereafter these parameters increase significantly. There is also an increase in myocardial blood flow, as measured by microspheres or by flowmetry of the left anterior descending. These changes are probably due to catecholamine release, brought about by a decreased distal perfusion pressure which also includes the adrenal glands. To conclude, there is a hyperdynamic cardiac function during cross-clamping of the thoracic aorta, mainly due to increased heart rate and a lower end-systolic volume of the left ventricle. The central venous pressure and pulmonary artery pressure are normal during cross-clamping. However, there is an increased resistance in the pulmonary vessels in the declamping phase. During this dynamic situation, it is important to define the time after cross-clamping when various haemodynamic parameters are measured. Reclamping of the thoracic aorta may have a detrimental effect on the cardiac function. Simultaneous with the increased cardiac output, there is an increase in blood flow of the common carotid artery in the experimental situation. Both in animal experiments and in the clinical situation, there is also an increased blood flow of the middle cerebral artery during cross-clamping of the thoracic aorta. In animal experiments, the percentual increase in blood flow in the brain is significantly less than the flow increase in the middle cerebral artery and the common carotid artery. This is probably due to cerebral autoregulation, which protects the brain from hyperperfusion. Most of the increase in cardiac output is therefore probably going in extracerebral structures. This can be recognised by the occurrence of oedema in the face and in the laryngeal region. An increased subcutaneous interstitial tissue pressure of the upper part of the body, including the neck, is seen.

Patients undergoing thoracic aortic surgery are at risk for cardiac complications due to the high incidence of previous myocardial infarction, congestive heart failure, angina pectoris, chronic obstructive pulmonary disease, renal dysfunction, and diabetes mellitus. A major concern in conjunction with proximal thoracic aortic clamping is the likelihood that the cardiac function in these patients will instantly deteriorate due to the temporary increase in afterload.

With a simplified definition, afterload could be expressed as the force of systemic vascular resistance that has to be overridden by the cardiac function in order to maintain blood flow. Besides various bypass techniques, a pharmacological approach to avoid the detrimental effects of this intervention may consist of inhalational anaesthetic agents, thoracic epidural anaesthesia, nitroglycerin, sodium nitroprusside, trimethapan or combinations of these treatments. The use of inhalational agents may cause vasodilation with increasing concentration at the expense of a depressed inotropic function. Usually isoflurane is utilised during aortic surgery due to the preservation of renal function compared to halothane. Thoracic epidural anaesthesia does not alter the haemodynamic effects of thoracic aortic cross-clamping, while the distal perfusion pressure is slightly higher after declamping. Nitroglycerin affects both afterload and preload with specific vasodilatory properties on the coronary arteries. However, the potency is only half compared to sodium nitroprusside.

Operation Indications and Future Aspects

The natural history of patients with TAAA treated non-operatively is unclear. A 2-year survival of only 24% has been reported, 38% of whom die of "rupture".[16] These data include patients with dissections, known to have a worse prognosis. Because the outcome of surgery is much better than conservative treatment, it is generally accepted that TAAAs with a diameter of more than 6 cm should be repaired. The main predictors for a negative outcome are compromised cardiopulmonary status (myocardial insufficiency, heart failure) or renal failure (creatinine higher than 150 μmol/l).[17] It was emphasised that outcome measures of quality of life are not available.

The endovascular revolution is already addressing the treatment of TAAAs. The general feeling was that a modular system would be developed with radiologists and surgeons working together, which would enable proximal fixation of a graft by endovascular techniques and perfusion of the vital organs through preconstructed side arms. The problem is the ability to enter the vital coeliac trunk, superior mesenteric and renal arteries in time for sequential graft placement before coagulopathy, renal failure and bowel ischaemia occur. There is also the dilemma of the excluded vital intercostal arteries. The future will show whether the endovascular technology will be able to equal the open technique in terms of morbidity and mortality.

Conclusion

Since the last workshop 5 years ago in 1992, progress has been made in the treatment of patients with TAAA.

Spinal fluid drainage combined with retrograde aortic perfusion reduce the incidence of paraplegia. Retrograde aortic and selective organ perfusion have contributed to decrease renal failure and intestinal ischaemia. Furthermore, the latter techniques significantly improve the haemodynamic changes during cross-clamping.

Despite this important progress, many problems have still to be solved in order to reduce the incidence of spinal cord ischaemia, renal failure, organ ischaemia, cardiopulmonary complications and mortality. Intraoperative monitoring of spinal cord function by means of motor-evoked potentials appears to be feasible and allows protective strategies during surgery to prevent spinal cord ischaemia.

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