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Surgical treatment of the ascending aorta and aortic arch with antegrade cerebral perfusion and moderate hypothermia

Tratamento cirúrgico da aorta ascendente e arco com perfusão cerebral anterógrada e hipotermia moderada

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Abstract

Objective: **To retrospectively evaluate the technique of antegrade cerebral perfusion via the innominate artery associated with moderate systemic hypothermia (28-30°C) in adults operated on for aneurysms or proximal aortic dissections.**

Method: **Twelve consecutive adult patients who presented with proximal aortic dissections or aneurysms were operated on. Of these, seven presented with aortic dissections and five presented with ascending aortic or aortic arch aneurysms. Arterial perfusion was achieved using an 8.0 mm PTFE graft anastomosed to the innominate artery; the brachiocephalic trunk was occluded proximally for antegrade cerebral perfusion. Systemic hypothermia of 28-30°C was used during circulatory arrest with the mean arterial pressure of the right radial artery maintained between 50-60 mmHg.**

Results: **There were no neurological or bleeding complications. In ten cases, the aortic valve was preserved by resuspension or remodeling. The mean time of circulatory arrest with antegrade cerebral perfusion was 24 minutes (range from 20 to 35 minutes).**

Conclusion: **Antegrade cerebral perfusion through the innominate artery associated with moderate hypothermia (28-30°C) seems to be effective to protect the central nervous system and possibly to avoid excessive bleeding in the post operative period.**

Descriptors: **Aorta, pathology. Aorta, surgery. Aneurysm dissecting, surgery. Cardiopulmonary bypass.**

Resumo

Objetivo: **Avaliar a técnica de proteção cerebral utilizando como via de acesso o tronco braquiocefálico para perfusão cerebral anterógrada e hipotermia moderada nas operações da aorta ascendente e arco aórtico.**

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Método: **Foram operados, consecutivamente, doze pacientes portadores de dissecção da aorta e/ou aneurismas. Destes, sete pacientes apresentavam dissecção de aorta e cinco eram portadores de aneurisma de aorta ascendente ou de arco aórtico. A perfusão arterial foi realizada por meio de enxerto de PTFE de 8,0 mm anastomosado ao tronco braquiocefálico. A hipotermia sistêmica foi de 28°C nasofaríngea. O tronco braquiocefálico foi ocluído para perfusão cerebral anterógrada. A pressão arterial média em artéria radial direita foi mantida entre 50-60 mmHg. A saturação transcutânea de oxigênio na artéria temporal e o BIS foram utilizados para monitorização contínua.**

Resultados: **Não houve nenhuma complicação neurovascular relacionada ao procedimento. A circulação extracorpórea foi mantida com fluxo adequado para manter pressão arterial de 50-60 mmHg, durante toda a operação. Em dez casos, a valva aórtica foi preservada com o emprego de técnicas de remodelagem ou ressuspensão. O tempo médio de parada circulatória total com hiperfluxo cerebral foi de 24 minutos (20 a 35 min).**

Conclusão: **A perfusão cerebral e a circulação extracorpórea por via anterógrada, através do tronco braquioocefálico, associadas à hipotermia moderada, mostraram-se eficientes na proteção do sistema nervoso e, possivelmente, evitaram as graves discrasias sanguíneas pós-operatórias.**

Descritores: **Aorta, patologia. Aorta, cirurgia. Aneurisma dissecante, cirurgia. Circulação extracorpórea.**

INTRODUCTION

Thoracic aortic diseases present with significant morbidity and mortality rates and are considered the most complex aortic diseases, causing severe consequences when treatment is not performed in time or when it is inadequate.

There have been great advances in the treatment of these diseases with the evolution of imaging techniques, bringing substantial improvements to surgical results and consequently, survival of patients.

In 1955 DeBakey et al. [1] reported initial experiences with the surgical treatment of aortic dissection. These authors described the excision of the dilated section, joining of the separated layers and restoration of the aortic blood flow with an end-to-end anastomosis.

The first replacement of the ascending aorta was performed by Cooley & DeBakey [2], which became the standard procedure for the treatment of acute dissections of the ascending aorta.

The procedure was accompanied by a high morbimortality rate until the 1980s. Ischemic injury to the central nervous system and uncontrollable perioperative hemorrhages constitute the main causes for the high death rates [3].

A great advance was the introduction by Griepp et al. [4] with deep hypothermia and cardiac arrest in the treatment of aortic arch disease. Cardiac arrest with deep hypothermia provides a bloodless, motionless operative field. Deep hypothermia protects the brain, the heart, the kidneys and other organs, presumably due to a reduction in the metabolic activity. However, clinical experience indicates that the time of cardiac arrest is important. The risk of neurological dysfunction increases significantly after 40 to 50 minutes and mortality increases greatly after 65 minutes of cardiac arrest [5].

Thus, other options for the surgical treatment of ascending aorta diseases were investigated with one being the establishment of a cannulation site of the arterial system. As there are two lumens, it is necessary that perfusion is adequate and through the true lumen of the aorta in order that the most important organs are satisfactorily perfused. The femoral artery was, for some time, the favorite site for arterial system cannulation. However, the presence of aorta-iliac peripheral artery disease, a distal extension of aortic dissection to these arteries and false lumen cannulation compromise adequate perfusion and make this option difficult to achieve or, even, counter-indicated.

Recently, successful approaches of the brachiocephalic trunk (BCT) and of the carotid, auxiliary or subclavian arteries to establish CPBes have been described in cases of acute aortic dissection and in some cases of true ascending aorta aneurysms with involvement of the aortic arch and the initial section of the descending aorta [6,7].

Apart from repair of the rupture point in the intima, another relevant factor in the results of surgical treatment resides in central nervous system protection during the interruption of the blood flow. Different methods of cerebral protection have been described; there are two options to perfuse brain tissue and thus increase the safety of the method. One of the options is selective anterograde perfusion using the BCT, common carotid or subclavian/ auxiliary arteries [8].

The other option is retrograde cerebral perfusion (RCP) by a cannula in the superior vena cava. RCP is a simple method that may contribute to brain preservation and extend the safety period of cerebral circulatory arrest. Although some authors have presented good clinical results with retrograde cerebral perfusion, others have described the poor cerebral protection offered by this method [9].

METHOD

Twelve consecutive patients suffering from aneurysms and/or dissections of the ascending aorta and aortic arch were operated. Seven patients had dissections and five had aneurysms. Of the dissections, six presented with acute ruptures and one presented with a chronic aneurysm of 8.6 centimeters. Within the group of patients with aneurysms, one case presented with Marfan's syndrome with dilation of the aortic root. Two cases of coronary artery bypass grafting were necessary as were two valve replacements due to severe aortic stenosis.

Seven patients were men and five were women. The mean age was 61 years old (34 to 78 years old). The most common symptom was thoracic pain reported by 75% of cases. None of the patients presented with signs of cerebral, myocardial or abdominal visceral ischaemia. All the patients were submitted to chest radiographs, transthoracic echocardiographs and tomography of the thorax using endovenous contrast. All the patients or guardians signed written consent forms.

The mean arterial pressure (MAP) was monitored via the right radial artery and cerebral oxygenation was monitored in all patients with the aim of preventing and correcting cerebral desaturation. For this, the Somanetics system was utilized which is based on spectroscopy (Figure 1). The normal values of saturation in this method vary between 60% and 70%. In general, the values obtained in the first reading before anesthesia induction are considered basal levels for each patient.

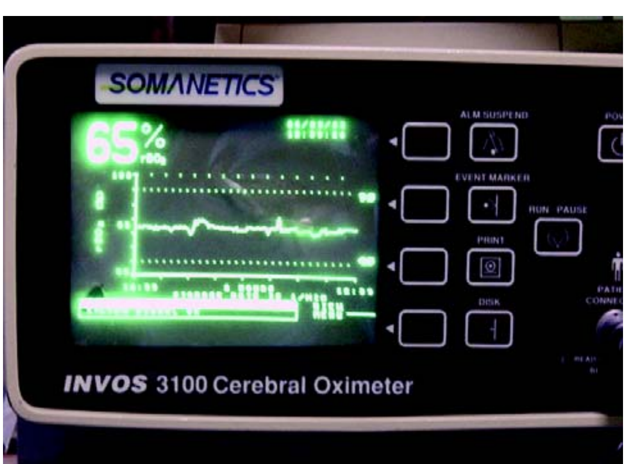

Fig. 1 – Somanetics system based on spectroscopy utilizing cerebral oximetry

Median thoracotomy with sternotomy was performed with dissection and repair of the BCT and preparation for venous cannulation. After systemic heparization (4 mg/kg body weight), an 8.0-mm PTFE graph was anastomised end-to-side to the BCT and connected to the arterial line of the (CPB) system (Figure 2). In all patients, the CPB and anterograde brain perfusion were performed through the 8-mm PTFE graft anastomosed to the BCT, preventing the necessity to transfer the cannula to the inorganic straight tubular graft after finishing the distal anastomosis. CPB was established using a membrane oxygenator maintaining a flow rate of 2.2 L/min/m^2 of body surface. Myocardial protection was by intermittent hypothermic sanguineous cardioplegia at 15-minute intervals through a cannula located in the coronary sinus.

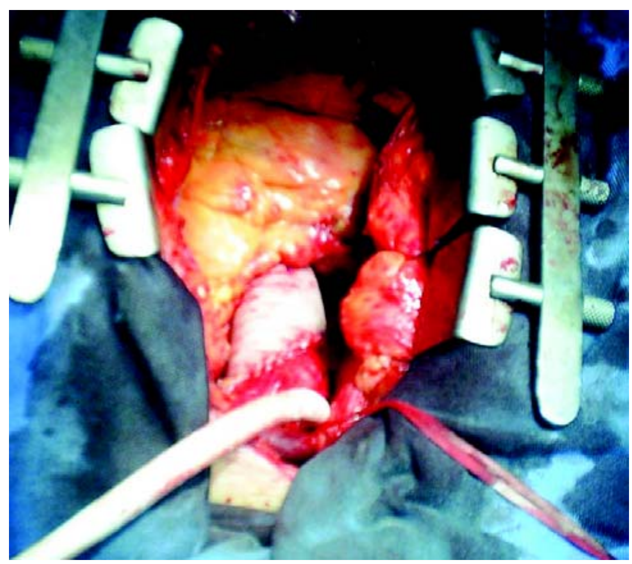

Fig. 2 – Median thoracotomy with sternotomy, repair of the BCT and preparation for venous cannulation. After systemic heparinization, the 8.0-mm PTFE graft is anastomosed end-to-side to the BCT and connected to the arterial line of the cardiopulmonary bypass system

The patients were cooled to a nasal-pharyngeal temperature of 28ºC. Control of pACO2 was achieved by the alpha-stat technique during moderate hypothermia. Hyperglycemia was aggressively treated during the operation with venous insulin.

Immediately after the start of total circulatory arrest, the origin of the BCT was occluded and hypothermic oxygenated blood was infused (25ºC) through the PTFE graft with a flow rate of between 300 to 500 mL/minute to maintain the MAP between 50 and 60 mmHg. With this type of cannulation and proximal conclusion of the BCT, it was possible to maintain brain perfusion during the time in which the aorta was open. The left carotid artery was clamped to avoid excessive reflux to the operative field.

During total circulatory arrest (TCA), brain flow was maintained with a MAP at around 50 to 60 mmHg and with a systemic temperature of about 24-28ºC. Oxygen saturation was monitored during all the period of total circulatory arrest and selective cerebral flow. There was an attempt to maintain the basal levels during all the intervention. The arterial flow was increased when there was a reduction of more than 15% of the initial level or when cerebral artery saturation was less than 50% of the absolute value. One of the advantages of the system is its dynamic nature.

When the CPB was reestablished, an occlusor is opened at the origin of the BCT and, gradually, the flow through the arterial line is increased to establish the total flow of the CPB and the patients are reheated to only 36ºC for cerebral protection.

On finishing CPB, before reversing anticoagulation with protamine sulfate, the PTFE tube used for perfusion was clamped, sectioned and sutured to the artery.

The surgical technique employed was adapted for each case according to the characteristics of dissection identified in the intraoperative period and the presence of involvement of valves or coronary arteries. Aortic valve recovery from the aortic failure was also possible in five patients. Treatment consisted in the suspension of aortic valve commissures a procedure performed in one case with Marfan's syndrome to remodel the aortic root (David I). In four patients, partial replacement of the aortic arch (hemi arch) was necessary.

The patients were submitted to neurological examinations using the Mini Mental State examination protocol in the preoperative period, at hospital release and also on the 30th postoperative day.

RESULTS

Perfusion of the BCT was possible in all cases. In all patients, dissection of the BCT was made without great difficulties, through a sternotomy with exposure of an adequate section of the artery to perform anastomosis to the PTFE graft possible. Additional incisions were not necessary.

The mean time of circulatory arrest was 24 minutes (20 to 35 minutes) and the mean time of CPB was 97 minutes (75 to 119 minutes).

There were no deaths, necessity of re-interventions due to bleeding, neurological or pulmonary complications. One patient with pre-operative renal failure and severe left ventricle dysfunction required haemodialysis for a period of three months.

In the neurological examinations, strokes were not observed nor were reversible neurological ischaemia deficits, transitory ischemic attacks or comas. Only two patients, one who was an alcoholic and the other with a history of psychiatric disease, presented with confused mental states. None of them presented with focal states. These conditions of confusion reverted within 48 hours and the patients returned to their pre-operative neurological states suggesting that these alterations are more related to the neurological condition than to alterations related to surgery.

DISCUSSION

Neurological protection provided during that period of hyperflow or total Circulatory arrest determines the success of aortic and great vessel operations. Protection provided by total circulatory arrest in isolation, for the aforementioned reasons, is not satisfactory [10].

The adult human brain corresponds to 2% of the body mass however, it consumes 15% of the total energy generated by the metabolism, with the metabolism of the organ seven times higher than of other organic systems. Approximately 60 mg of glucose and 3-4 mL of oxygen per minute are necessary for 100 g of tissue. The brain can tolerate an acute reduction of up to 40 to 50% in its blood flow during normothermia. Below this, the functional and pathological changes in the ATP reserve and the accumulation of glutamate occur progressively [11].

Glutamate and aspartate are substances utilized as messengers for interneuronal communications. After their release to the intercellular space, glutamate is rapidly converted to glutamine and re-enters the neuron to be utilized. Any cause of interruption of this conversion leads to an accumulation of glutamate in the intercellular space where, at high concentrations, it acts as a neurotoxic drug, opening calcium its channels, causing inflow of calcium and activation of several enzymes leading to autodigestion and cell death [11].

During moderate hypothermia, autoregulation of the brain flow is maintained at pressures of up to 30 mmHg. A loss of metabolic the demand compromises autoregulation. The non-pulsating flow of the heart-lung machine also compromises the autoregulation system, increasing resistance as time passes. Consequently, greater perfusion pressures are necessary for adequate perfusion after a long period of CPB [12].

We identified two types of brain injuries related to CPB. Overall ischaemia of the brain consequent to interruption of flow or inadequate flow which is seen by means of temporary neurological dysfunction and detectable by neuropsychological tests, especially those that evaluate memory even in coma [10].

A second type of brain injury is seen with small local injuries caused by infarction. This type of lesion is consequent to the presence of debris or thrombi in the aorta and is generally independent of per-operative brain protection [10]. For this a careful pre-operative evaluation of the great vessels is performed (Echo Doppler). If the great vessels are compromised, we believe that the best option is the subclavian artery.

Pathogenesis of ischaemic brain lesions is in three distinct phases: a depolarization phase, in which an accumulation of adenosine monophosphate (AMP) and nitric oxide - powerful vasodilators - occurs in the intercellular space. Vasodilation causes greater quantities of glucose to be available for anaerobiosis. This process is accelerated by hyperglycemia. The inability of the brain to use lactate and the absence of blood flow to transport it lead to its accumulation and an eventual drop in the intercellular pH [10]. For this reason, per-operative and immediate post-operative glycemia must be ostensibly controlled.

The second phase or biochemical cascade phase is characterized by the accumulation of neurotransmitters in the intercellular space, opening calcium channels, leading to a massive inflow of calcium ions, activating intercellular enzymes with disastrous consequences [10].

The third phase, characterized by reperfusion injury, occurs when the circulation is re-established and may be the most important phase of injury, where adequate maintenance of oxygen seems to be critical. Leukocyte infiltrations and inflammatory reactions mediated by cytokines significantly participate in this phase [10]. We re-initiate hypothermic flow and maintained this for five minutes. Only after this period do we initiate gradual systemic re-warming.

Different authors have described advantages and disadvantages of specific methods of protection of the central nervous system, levels of hypothermia and perfusion methods during CPB including total circulatory arrest (TCA) combined to deep hypothermia, hypothermic TCA with retrograde cerebral perfusion and, finally, hypothermic TCA with anterograde cerebral perfusion by the brachiocephalic branch/carotid artery, or even, by the subclavian axillary axis [13].

Hypothermic TCA is considered the method of choice for cerebral protection, because it facilitates inspection of the arch when there are intimal lesions allowing access to its entire length including the proximal portion of the descending aorta and impeding that aortic clamping close to the arch causing sites of dissection near to the distal anastomosis [13]. The technique consists in establishing CPB by the cannulation of the right atrium-femoral artery, slow cooling to between 18 and 20ºC (a temperature at which the metabolic rate is 18% of normal) and the use of ice packs for topical cooling of the head and neck [14].

The utilization of the femoral artery was, for a long time, suggested as an option for the cannulation of the arterial system. In this case, retrograde systemic perfusion may cause some inconveniences such as retrograde cerebral emboli due to debris. The most important factor when perfusion is performed through the femoral artery is the adaptation of flow through the true lumen as, in 42% of cases, the flow is achieved through the false lumen, and when this occurs it can cause bad perfusion of the important organs [15].

Contraindications such as severe atherosclerotic aorta-iliac decease and peripheral atherosclerotic disease make cannulation of the femoral artery prohibitive. It is also not uncommon to have complications inherent to the procedure including ischaemia of the lower limbs and the necessity of performing arterioplasties to correct the insertion site of the arterial cannula, lymphocele and local infections, principally in obese patients [16].

Deep hypothermia is the main feature of cerebral protection in this method. The protective effect of hypothermia is based on a reduction in the intercellular enzymatic activity associated to temperature. Experimentally, hypothermia has provided better cerebral protection than that obtained by nervous system depressant agents. Clinical and experimental evidence has demonstrated a period of safe circulatory arrest of approximately 40 minutes, with esophageal temperatures at around 18ºC. There is a progressive increase in risk for ischaemic lesions if the time exceeds this limit [17].

There is a consensus that lower temperatures offer greater protection when longer periods of circulatory arrest are predicted. This level seems to be safe to promote total circulatory arrest of up to 40 minutes in respect to neurological morbidity [11]. The ice placed on the head can promote better cranial hypothermia. This active cooling takes at least 30 minutes. Hemodilution also exerts a protective factor on the brain during hypothermia [18]. Warming should be slow, at around one degree centigrade each three minutes, to minimize hemolysis and the harmful effects on regulation factors.

Cerebral retroperfusion (RPC) by the Superior vena cava during TCA provides sustained cerebral cooling making this perfusion effective to maintain nerve tissue at low temperatures during the period of arrest. It also presents the advantages of removing metabolites resulting from ischaemia, removing air of even debris with emboligenic potential and allows perfusion of nutritional substrates during TCA [9].

However efficiency of oxygen supply is questionable. Its employment has become questionable due to its limitations, such as insufficient cerebral flow and nonhomogeneous intracerebral distribution, explained by the presence of veno-venous shunts, confirmed in anatomic studies; this is the reason that only a small fraction of perfusate effectively reaches brain tissue [19] as well as due to the presence of valves in the jugular system [20], and is associated with brain edema and bleeding in the operative field. Increasing the pressure on the entire venous system, seems to have better retrograde cerebral perfusion, however, this maneuver seems to be associated to a significant retention of fluids, as well as from increasing the risk of brain edema. The pressure of retrograde perfusion should not pass 20 mmHg [21].

Currently, PCR is indicated primarily for the prevention of neurological injury in patients with high risks of embolism due to the presence of thrombi or atheroma in the aorta. It may be utilized for short periods, before initiating anterograde perfusion to remove debris from the great vessels and their branches.

Cerebral protection with anterograde perfusion during TCP may be attained through BCT, the carotids and subclavian or axillary arteries. This technique presents advantages such as avoiding the handling of the femoral artery which is often compromised by dissection, to maintain the flow in an anterograde direction through the true lumen and not to require deep hypothermia which minimizes the aforementioned serious consequences [22]. Additionally, this technique eliminates the bad perfusion of the important organs and the creation of new reentry points due to increases in the pressure in the false lumen [23]. In this technique, the temperature is reduced to approximately 28ºC; TCP is established, the BCT is clamped at its origin and the flow is adjusted to maintain a MAP of around 50-60 mmHg. Management of $PaCO_2$ by the alpha-stat technique during moderate hypothermia is extremely important during TCA. Hyperglycemia and anaerobic glucolysis lead to an accumulation of lactate and intracellular acidosis during the period of circulatory arrest. Thus, hyperglycemia must be aggressively treated during the operation using venous insulin.

The use of moderate systemic hypothermia may reduce the risks of excessive bleeding and minimize complications associated with prolonged perfusion, such as capillary leakage syndrome by avoiding the low temperatures and the long periods of cooling and warming necessary with deep hypothermia and circulatory arrest.

Physiological principles of cerebral autoregulation that exist during normothermia are maintained during perfusion with moderate hypothermia. The cerebral blood flow depends on the metabolism of the brain. If the metabolism is high, the cerebra vascular resistance drops and the cerebral blood flow increases. This is known as flow-metabolism coupling and remains intact during perfusion with moderate hypothermia. In autoregulation, the pressure-flow relationship or the ability to maintain the cerebral blood flow constant, in spite of the wide range of mean arterial pressures, also remains intact during perfusion with moderate hypothermia. The cerebral vasculature maintains its ability to dilate during the low pressures of perfusion and contract when the perfusion pressure is high. At temperatures of less than 22ºC and/or with the management of pH stat, these advantages are lost. Hypothermia and anterograde cerebral perfusion are the most efficient methods of maintaining the aerobic glucolysis in the presence of low flows [24].

Different regions of the brain present with substantial variations of energy needs. The gray matter needs more energy than the white matter, the cortex more than the basal part, active neurons more than quiescent neurons. Thus, the earliest signs occur in the regions of the brain with the greatest metabolic activity, which are maintained even with the utilization of deep hypothermia. In experimental models, the earliest histologic signs of ischemia can be detected anatomically in the hippocampus with clinical signs such as recent memory loss in individuals submitted to TCA [25]. In our evaluation no patients presented with these deficits.

Perfusion through the BCT provides a continuous oxygen supply to the supra-aortic region and collateral vessels to the lower part of the trunk. The observation that no neurological abnormality occurred in our small series may also be related to the short period of arrest (only 24 minutes). On measuring the cerebral saturation in real time, immediate intervention in the blood flow is possible preventing hypoperfusion and cerebral hypoxia.

CONCLUSIONS

In spite of the small initial series, we conclude that the method utilized for perfusion through a PTFE graft anastomosed to the brachiocephalic trunk is simple, reproducible and presents a low incidence of complications. There are advantages in providing a satisfactory anterograde blood flow and also to allow anterograde cerebral perfusion with higher temperatures, avoiding the neurovascular and dyscrasic complications.

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