Brain Protection in Type A Aortic Dissection

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Abstract

Abstract Due to the technical necessity to enter the aortic arch during surgery for aortic dissection type A, the brain must be protected optimally to avoid damage to our most precious organ. The different options are reviewed starting with deep hypothermic circulatory arrest which was the first technique described to protect the brain. Its major advantage is the bloodless surgical field and its simplicity but the time constraints limit its application in complex and extended repairs. Therefore antegrade cerebral perfusion has actually become much more popular because this technique allows for much longer arrest periods in which the brain is perfused in a physiological manner reducing the cerebral complications after surgery. Pros and cons of the existing techniques are discussed.

Keywords

Type A dissection, aortic dissection, circulatory arrest, antegrade cerebral perfusion, hypothermic arrest

Introduction

Surgery for type A dissection is still today a very challenging and complex procedure. An important contributing factor to this complexity is, amongst others, the necessity during the surgical repair to enter the aortic arch and interrupt partially or totally the cerebripetal blood flow. Therefore adequate cerebral protection is one of the cornerstones towards success. In this paper, we will give an overview of the possible techniques and pitfalls in brain protection related to type A aortic dissection.

Basic physiology and energy metabolism of the central nervous system

Despite the fact that only 2% of our total body weight constitutes of brain tissue, its metabolic demands are high. Nearly 20% of the total oxygen and 20% of the glucose consumption is utilized by our central nervous tissue. Most of the oxygen and glucose consumption is used to maintain the membrane potential through Na^{+}/ K^{+} -ATPase and other processes involved in ion transport across membranes. The brain energy source does not come from fatty acids but is almost exclusively based on saccharide sources with a daily consumption of glucose of about 120 g. The interplay between neurons and astrocytes is particularly important in the energy metabolism of the brain: astrocytes are primarily anaerobic in terms of ATP generation via anaerobic glycolysis and net lactate extrusion while neurons primarily have a high level of aerobic mitochondrial metabolism (1). Astrocytes, specialized glial cells metabolically supporting the neurons and outnumbering neurons by fivefold, mainly consume glucose while neurons rely primarily on lactate and pyruvate, substances released by astrocytes into the extracellular space and absorbed into the neurons. The higher the activity of the neuron, the higher the production of lactate in the astrocyte. Glutamate, the most important neurotransmitter within the central nervous system, is transported from the synaptic cleft into the astrocytes. These cells reform glutamate into glutamine and return it back to the neuron for further utilization. On the other hand is our brain very sensitive to deficits of oxygen and glucose. Even after a few seconds a shortage of oxygen may cause unconsciousness and after about 5 minutes irreversible neuronal damage may occur at normothermia. This low sensitivity to hypoxia is evident by the well-known capability to culture astrocytes for up to 24 hours from adult brain tissue whereas neurons survive less than 5 minutes in an anoxic environment (1).

In healthy adults the cerebral autoregulation keeps the cerebral blood flow constant throughout a range of perfusion pressures between 50 and 150 mm Hg (2). These limits decrease to 30 and 100 mm Hg at 22° C brain temperature but at lower temperatures autoregulation is terminated and cerebral blood flow becomes directly proportional to cerebral perfusion pressure (3).

Related to aortic arch surgery causes of neurologic complications are either thromboembolic (atheroma, debris, air) leading to focal defects or interruption of the normal cerebral perfusion with insufficient cerebral protection leading to more global injuries. Both these mechanisms of injury need to be tackled during arch repair. In acute dissection patients atherosclerosis is mostly absent. No need to say that transient and/or permanent neurological deficits will have a negative impact on short- and long-term survival.

Brain protection techniques in type A aortic dissection

General aspects

We need to clarify first some important general aspects like temperature monitoring, clamping of the aorta or not and brain monitoring.

During cardiopulmonary bypass temperature monitoring of the core of the body including the head and brain, is used in general because this core compartment will undergo fastest temperature changes due to the high flow rate into the mediastinal organs. It can be measured at different reliable sites such as tympanic membrane, nasopharynx and oesophagus (4). Nasopharyngeal temperature is now accepted by most surgeons as a good representative of the brain temperature. Pulmonary artery catheter can also be used to measure the core temperature but due to its invasiveness and costs it is not routinely used. Rectal and bladder temperature, often used in general cardiac and aortic surgery lag behind central monitoring sites and they certainly do not indicate accurately the cerebral temperature. Moreover they are affected by the presence of stools and bacteria that generate heat or by the production of urine. Skin temperature is not related to core temperature and is confounded by several factors such as ambient temperature. Blood temperature in the arterial line from the oxygenator is a also very good reference of cerebral temperature (5). The best indicator of cerebral cortical temperature is measurement of jugular bulb temperature (5) though it is rarely used in practice. Most surgical centers use a combination of the aforementioned temperature monitoring sites. In the literature there is a lack of uniformity making the interpretation of the results difficult and sometimes confounding. We share the opinion of Saad H et al (6) that temperature management strategies during cardiopulmonary bypass and more specific using hypothermic circulatory arrest (HCA), rely primarily on personal or institutional preferences rather than solid scientific basis.

A second technical important question is whether ascending aortic clamping during the surgical repair of type A aortic dissection is safe and mandatory. In chronic and acute cases, most surgeons will clamp the ascending aorta and proceed with cooling and meanwhile perform the root repair. However because clamping can pressurize the false lumen in the acute setting leading to partial or even total malperfusion of the brain (7), clamping can only be done if adequate and appropriate intra-operative monitoring allows for rigorous and reliable real-time evaluation of the brain perfusion to eventually adapt perfusion strategy immediately. On the other hand many experienced aortic surgeons counsel against clamping in acute type A and proceed directly with cooling to do the open distal reconstruction first, then followed by the proximal repair during the rewarming phase (8). In the chronic cases aortic clamping is less risky but it also requires adequate monitoring of the brain.

Minimal intra-operative monitoring during surgery for type A aortic dissection encompasses bilateral radial artery pressure (or cannula-based perfusion pressure monitoring if axillary cannulation is used) and forehead regional near infrared spectroscopy (NIRS). We have to keep in mind that NIRS does not provide information in the basilar artery region. Some exceptional centers also use transcranial doppler monitoring indicating the flow through both middle cerebral arteries. Another option is the use of electroencephalography to demonstrate electrical brain silence and represent neural-cell arrest during HCA. Iatrogenic brain malperfusion can be avoided by switching from femoral to axillary artery although in the context of acute type A dissection initial femoral cannulation remains reasonable even in the 21st century (8).

There has been much debate about the ideal arterial cannulation site related to acute type A dissection. Nonrandomized studies have shown that the axillary cannulation is related with better neurological outcome (9,10, 11) but some authors including ourselves consider femoral artery cannulation as safe in aortic dissection (12): it is quick and reliable but absolutely necessitates adequate intra-operative monitoring as said before to allow for a prompt switch from cannulation site if signs of brain malperfusion occur. Urbanski et al. demonstrated that even with direct cannulation and perfusion of one or both carotid arteries plus distal aortic perfusion, e.g. through a femoral artery, perfect results can be obtained (13). Direct aortic arch cannulation of the ascending aorta can be performed in chronic as well as acute dissection (14). In certain conditions transapical cannulation can be performed as a last resource aiming at the introduction of the cannula directly into the true lumen in emergent cases.

Because there is clinical consensus that an open distal anastomosis in acute type A dissection with inspection of the arch and arch vessels is an absolute minimum (8), there is a need to interrupt partially or totally the cerebripetal blood flow. Therefore the brain has to be protected. In general, the ideal brain protection technique should be simple to applicate and learn (very often acute dissection operations are performed by the youngest surgeons), effective and reliable. We have at our disposal three basic techniques:

1.Hypothermic circulatory arrest (HCA)

This technique was introduced in the 1950s and further popularized in the 1970s, even today a lot off centers have very positive clinical results with only HCA (15). It is based on the ability of hypothermia to reduce the metabolic rate of all tissues including the central nervous system. During cardiopulmonary bypass core temperature can vary from normothermia (37° C), mild hypothermia (32-35° C), moderate hypothermia (28-32° C) to deep hypothermia ($<$ 28° C). Profound hypothermia suppresses cerebral metabolism enough to allow a short period of total circulatory arrest during which the aortic repair can be performed. Despite many negative critiques still today a lot of surgeons throughout the world use HCA as their preferred method of choice because it is simple and allows for a complete bloodless surgical field also free of cannulas. Despite its simplicity, it demands for attentive perfusion and monitoring techniques with slow, gradual and thorough cooling ($>$ 30 minutes) to avoid oesophageal-blood gradients of $>$ 10 ° C. Rewarming must also be gradual with a temperature gradient of less than 10 ° C to avoid damage and to optimize oxygen delivery to the vulnerable brain intra- and post-operatively. It is necessary to flood the operative field continuously with CO_2 . Randall Griepp, the promotor of HCA, advises to cool thoroughly to prevent a temperature rise of the brain during the HCA interval and to pack the head in ice in order to prevent undesirable rewarming (16). To obtain maximal metabolic suppression Griepp recommends cooling until the oesophageal temperature reaches 10° to 13° C (16). This level of deep cooling is nowadays still used by a lot of surgeons in the US but it is our impression that in Europe and Japan, the temperature at which the body circulation is arrested, is higher ($20 - 25$ ° C, even 28 ° C) also obtaining good clinical results (17). Even tepid HCA (32° C) seems to compare favourably with deep HCA (20-25° C) (18). Immediately after a period of HCA follows a period of reactive hyperaemia or cerebral hyperperfusion followed by several hours of increased cerebrovascular resistance during which brain oxygen extraction is increased but cerebral blood flow may be inadequate (19).

Certainly the main drawback of HCA is that the safe duration of the arrest period is limited to about 20 to 25 minutes despite meticulous perfusion and monitoring approaches (20). Hypothermia will never reduce the cerebral metabolism to nil. The arrest duration is the single largest operative determinant of neurologic outcome. If the arrest time is longer than 20 to 25 minutes, it will result in an increase in neurological dysfunctions and when it is longer than one hour, the risk of stroke and mortality increases sharply (21). In our opinion this time restriction of 20 minutes is sufficient only to perform an open distal anastomosis at the base of the innominate artery or a hemi-arch replacement, even in the hands of the most technically skilled and experienced surgeons. If a more extensive reconstruction is necessary because of additional arch tears, aneurysmal aortic arch or when the surgeons wants to perform a prophylactic repair in view of future dilatations (e.g. in connective tissue disorders or in young patients), adjunctive brain protection techniques are absolutely mandatory. It is a false idea that the safe arrest duration of 20 minutes can be prolonged with pharmacologic adjuncts such as barbiturates.

Due to the obligatory slow cooling and slow warming the second drawback of HCA is the increased cardiopulmonary bypass time. This may lead to a higher evidence of neurologic complications in the early postoperative period and a decrease in quality of life in the long-term period (22). Coagulation disturbances are also related to the use of HCA. There are three mechanisms that contribute to the temperature-related coagulopathy: platelet and clotting factor dysfunction and the fibrinolytic activity. Nowadays these coagulopathies are dealt with more easily since we have at our disposal more effective pharmacological agents as well as platelet and plasma transfusions and other local hemostatic agents.

2.Retrograde cerebral perfusion (RCP)

This technique was first described by Ueda (23) and aims at prolonging the safe duration of HCA, flushing embolic debris and air out of the brain vessels and removing toxic metabolites. A few years later it was demonstrated in different animals that RCP does not result in effective cerebral perfusion (24,25): RCP does not provide adequate nutritive delivery to meet cerebral metabolic demands. Also Ehrlich demonstrated ineffective cerebral flow during RCP (26). Despite the lack of any benefit in outcome using RCP, some surgeons still today use it throughout their aortic arch replacements because some large clinical series demonstrated good results (27). On the other hand the group of Birmingham UK could not demonstrate a cerebral metabolic, neurologic of neuropsychological outcome benefit using RCP related to arch surgery (28,29). A potential disadvantage is increasing brain oedema exacerbating cerebral injury (30). RCP seems to be fading away gradually nowadays.

3.Antegrade selective cerebral perfusion (ASCP)

Using this technique which mimics physiological perfusion, some or all of the cerebripetal arch arteries are antegradilly perfused using oxygenated cold blood. This is done via balloon-tipped perfusion catheters introduced during short periods of systemic circulatory arrest or via angled cannulae introduced through the vessel wall without arrest. ASCP being propagated first by Bachet (31) and later-on especially Kazui (32) has been shown to be very successful in outcome and therefore it is adapted by most surgeons nowadays as there are almost no longer time constraints (33,34). There is clinical evidence that ASCP affords superior brain protection compared to HCA alone or HCA combined with RCP. This is based on the continuation of aerobic metabolism during the perfusion period and a less marked hyperaemic response compared to HCA (35). Of course the operative field is not bloodless and even more crowed due to the presence of different cannulae, but these minimal drawbacks certainly do not outweigh the tremendous benefits of a much longer possibility to repair and reconstruct the arch and side branches. There are now several variants of ASCP illustrating the unknown and lacking optimal perfusion characteristics of ASCP, still today despite the fact that the technique is three decades old. Most surgeons now use separate cannulation (directly or endoluminally) of the innominate artery (eventually via the right axillary artery) together with the left common carotid artery (or clamping of the base of the innominate artery when the right axillary artery is used as arterial inflow), with occlusion (by a clamp, balloon or snare) of the left subclavian artery to avoid a steal phenomenon. Most authors will now use a flow of 10 cc/kg/min corresponding roughly to normal blood flow under normothermia but this flow rate might be too high under anaesthesia and profound hypothermia leading eventually to cerebral oedema. In our centre we advocate the combination of deep HCA (circulatory arrest at 20 ° C nasopharyngeal temperature) and ASCP at a flow rate of 10 cc/kg/min in all arch cases especially in every acute type A dissection because this pathology may yield unexpected surprises in the arch and in doing so, it allows all surgeons, even those with limited experience to obtain good results. Bihemispheric antegrade perfusion via right and left common carotid arteries is now routine in most centers since in 2% to 15% the circle of Willis is incomplete and it has been shown that bihemispheric perfusion has a significant favourable impact on hospital mortality (36). Drawbacks are the necessity to manipulate and cannulate the cerebral vessels with the potential risk of dislodging atherosclerotic debris. It is however important to emphasize that atherosclerosis and acute dissection not often come about simultaneously. In chronic cases there is more time available to illustrate the presence of calcifications, atherosclerotic debris or clots and adapt the cannulation and perfusion strategy. Surgeons and perfusionists have the possibility to change a number of parameters such as flow rates, pressures, the number of vessels perfused, temperature of the perfusate and core temperature and this has led to a high variability and a lack of standardisation between different institutes. Also here the avoidance of air emboli is important as is the use of intraoperative CO_2 but this is not different from HCA. A lot of questions remain unanswered today such as which is the optimal core temperature before the circulatory arrest can be instituted (3). Over the last decade we see a trend towards a slow rise in the temperature at which the circulation is arrested while the perfusate of the brain is at a lower temperature level. This can be an explication why the incidence of spinal cord problems and renal failure is now increasing in clinical series. Continuous corporeal perfusion through an endoluminal perfusion-occlusion cannula in the proximal descending aorta or via the femoral artery could minimalize the deleterious ischemic effects on the spinal cord, kidneys and guts (37). Other unknown factors, still today are the optimal perfusion pressure, the optimal temperature of the cerebral/body perfusate and pH management. Bachet who applied HCA at 25-28° C, perfused the brain at 6 - 12° C (38). Kazui proposed higher perfusion temperatures at 20 – 22° C (39). For most authors, the basic criterion of sufficient perfusion to the brain is a restoration of a mean right radial artery pressure of 40-70 mmHg but for technical reasons, in case of axillary cannulation, the radial artery pressure might not correlate with the right carotid pressure necessitating additional assessment (3). Apart from the aforementioned monitoring techniques, measurement of jugular bulb venous oxygen saturation can be a reliable tool for the estimation of adequate cerebral perfusion (40).

4.Which is the best cerebral protection strategy in type A aortic dissection?

Technically surgery for acute and chronic type A aortic dissection is complex and has to be extended at least into the proximal arch, sometimes further downstream. This demands for opening the arch and arresting the circulation. There is a lack of randomized controlled trials comparing the three aforementioned cerebral protection techniques. HCA appears safe for short arrest durations but if the anticipated arrest time is longer than 20 to 25 minutes (which is too short to perform complex arch repair in a setting of acute type A dissection), most surgeons will rely on ASCP due to the superior outcomes. In a large meta-analysis Tian et al. clearly showed that moderate hypothermic circulatory arrest in combination with selective antegrade cerebral perfusion is the most optimal way to protect the brain in arch surgery (41). Therefore we advocate in type A dissection a modification of this technique: we cool the patient first to 20° C core temperature, then arrest the circulation and install ASCP. This dual protection strategy allows for a very extended and safe time period in which the arch can be tackled minimizing cerebral damage, eventually anticipating technical difficulties with an almost zero risk of spinal and renal function problems. It further allows for meticulous surgical technique and the benefits of this will be translated in less haemostatic problems at the end and therefore not necessarily an extra prolongation of ECC-time.

AUTHOR CONTRIBUTIONS

Marc Schepens: concept/design, drafting, revision

Eric Graulus: drafting, revision

REFERENCES

1.Turner DA, Adamson DC. Neuronal-astrocyte metabolic interactions: understanding the transition into abnormal astrocytoma metabolism. J Neuropathol Exp Neurolog 2011;70(3):167-76.

2.Armstead WM. Cerebral blood flow autoregulation and dysautoregulation. Anesthesiol Clin 2016; 34(3):465-477.

3.Harrington DK, Fragomeni F, Bonser RS. Cerebral perfusion. Ann Thorac Surg 2007;83(2):799-804.

4.Whitby JD, Dunkin LJ. Cerebral, oesophageal and nasopharyngeal temperatures. Br J Anaesth 1971;43(7):673-676.

5. Nussmeier NA. Management of temperature during and after cardiac surgery. Tex Heart Inst J 2005;32(4):472-76.

6. Saad H, Aladawy M. Temperature management in cardiac surgery. Glob Cardiol Sci Pract 2013;2013(1):44-62.

7.Robicsek F, Guarino RL. Compression of the true lumen by retrograde perfusion during repair of aortic dissection. J Cardiovasc Surg (Torino) 1985;26(1):36-40.

8.Bonser RS, Ranasinghe AM, Loubani M, Evans JD, Thalji NM, Bachet JE, Carrel TP, CzernyM, Di Bartolomeo R, Grabenwöger M, Lonn L, Mestres CA, Schepens MA, Weigang E. Evidence, lack of evidence, controversy, and debate in the provision and performance of the surgery of acute type A aortic dissection. J Am Coll Cardiol 2011;58(24):2455-74.

9.Pasic M, Schubel J, Bauer M, Yankah C, Kuppe H, Weng YG, Hetzer R. Cannulation of the right axillary artery for surgery of acute type A dissection. Eur J Cardiothorac Surg 2003;24(2):231-6.

10.Reuthebuch O, Schurr U, Hellermann J, Prêtre R, Künzli A, Lachat M, Turina MI. Advantages of subclavian artery perfusion for repair of acute type A dissection. Eur J Cardiothorac Surg 2004;26(3):592-8.

11. Moizumi Y, Motoyoshi N, Sakuma K, Yoshida S. Axillary artery cannulation improves operative results for acute type A aortic dissection. Ann Thorac Surg 2005;80(1):77-83.

12.Fusco DS, Shaw RK, Tranquilli M, Kopf GS, Elefteriades JA. Femoral cannulation is safe for type A dissection repair. Ann Thorac Surg 2004;78(4):1285-9.

13. Rylski B, Urbanski PP, Siepe M, Beyersdorf F, Bachet J, Gleason TG, Bavaria JE. Operative techniques in patients with type A dissection complicated by cerebral malperfusion. Eur J Cardiothorac Surg 2014;46(2):156-166.

14.Jakob H, Tsagakis K, Szabo A, Wiese I, Thielmann M, Herold U. Rapid and safe direct cannulation of the true lumen of the ascending aorta in acute type A aortic dissection. J Thorac Cardiovasc Surg 2007;134:244-5.

15.Ziganshin BA, Elefteriades JA. Deep hypothermic circulatory arrest. Ann Cardiothorac Surg 2013;2(3):303-15.

16.Griepp RB. Cerebral protection during aortic arch surgery. J Thorac Cardiovasc Surg 2003;125:S36-8.

17.Di Eusiano M, Schepens MA, Morshuis WJ, Di Bartolomeo R, Pierangeli A, Dossche KM. Antegrade selective cerebral perfusion during operations on the thoracic aorta: factors influencing survival and neurologic outcome in 413 patients. J Thorac Cardiovasc Surg 2002;124(6):1080-6.

18.Watanabe G, Ohtake H, Tomita S, Yamaguchi S, Kimura K, Yashiki N. Tepid hypothermic (32° C) circulatory arrest for total aortic arch replacement: a paradigm shift from profound hypothermic surgery. Interact Cardiovasc Thorac Surg 2011;12(6):952-5.

19.Kawata H, Fackler J, Aoki M, Tsuji MK, Sawatari K, Offutt M, Hickey PR, Holtzman D, Jonas RA. Recovery of cerebral blood flow and energy state in piglets after hypothermic circulatory arrest versus recovery after low-flow bypass. J Thorac Cardiovasc Surg 1993;106(4):671-85.

20.McCullough JN, Zhang N, Reich DL ,Juvonen TS, Klein JJ, Spielvogel D, Ergin MA, Griepp RB. Cerebral metabolic suppression during hypothermic circulatory arrest in humans. Ann Thorac Surg 1999;67(6):1895-9.

21.Svensson LG, Crawford ES, Hess KR, Coselli JS, Raskin S, Shenaq SA, Safi HJ. Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. J Thorac Cardiovasc Surg 1993;106(1):19-31.

22.Kamenskaya OV, Klinkova AS, Chernyavsky AM, Lomivorotov VV, Meshkov IO, Karaskov AM. Deep hypothermic circulatory arrest vs. antegrade cerebral perfusion in cerebral protection during the surgical treatment of chronic dissection of the ascending and arch aorta. J Extra Corpor Technol 2017;49(1):16-25.

23.Ueda Y, Miki S, Kusuhara K, Okita Y, Tahata T, Yamanaka K. Surgical treatment of aneurysm or dissection involving the ascending aorta and aortic arch, utilizing circulatory arrest and retrograde cerebral perfusion. J Cardiovasc Surg (Torino) 1990;31(5):553-8.

24.Boeckxstaens CJ, Flameng WJ. Retrograde cerebral perfusion does not protect the brain in non-human primates. Ann Thorac Surg 1995;60(2):319-28.

25.Ye J, Yang L, Del Bigio MR, Summers R, Jackson D, Somorjai RL, Salerno TA, Deslauriers R. Retrograde cerebral perfusion provides limited distribution of blood to the brain: a study in pigs. J Thorac Cardiovasc Surg 1997;114(4):660-5.

26.Ehrlich MP, Hagl C, McCullough JN, Zhang N, Shiang H, Bodian C, Griepp RB. Retrograde cerebral perfusion provides negligible flow through brain capillaries in the pig. J Thorac Cardiovasc Surg 2001;122(2):331-8.

27.Bavaria JE, Woo YJ, Hall RA, Wahl PM, Acker MA, Gardner TJ. Circulatory management with retrograde cerebral perfusion for acute type A aortic dissection. Circulation 1996;94(Suppl 2):173-6.

28.Bonser RS, Wong CH, Harrington D, Pagano D, Wilkes M, Clutton-Brock T, Faroqui M. Failure of retrograde cerebral perfusion to attenuate metabolic changes associated with hypothermic circulatory arrest. J Thorac Cardiovasc Surg 2002;123(5):943-50.

29.Harrington DK, Bonser M, Moss A, Heafiled MT, Riddoch MJ, Bonser RS. Neuropsychometric outcome following aortic arch surgery: a prospective randomised trial of retrograde cerebral perfusion. J Thorac Cardiovasc Surg 2003;126(3):638-44.

30.Wong CH, Bonser RS. Retrograde cerebral perfusion: clinical and experimental aspects. Perfusion 1999;14(4):247-56.

31.Bachet J, Guilmet D, Goudot B, Termignon JL, Teodori G, Dreyfus G, Brodaty D, Dubois C, Delentdecker P. Cold cerebroplegia. A new technique of cerebral protection during operations on the transverse aortic arch. J Thorac Cardiovasc Surg 1991;102(1):85-94.

32.Kazui T, Kimura N, Yamada O, Komatsu S. Surgical outcome of aortic arch aneurysm using selective antegrade perfusion. Ann Thorac Surg 1994;57(4):904-11.

33.Kazui T, Washiyama N, Muhammad BA, Terada H, Yamashita K, Takinami M. Improved results of atherosclerotic arch aneurysm operations with a refined technique J Thorac Cardiovasc Surg 2001;121(3):491-9.

34.Di Eusiano M, Schepens MA, Morshuis WJ, Dossche KM, Di Bartolomeo R, Pacini D, Pierangeli A, Kazui T, Ohkura K, Washiyama N. Brain protection using antegrade selective cerebral perfusion: a multicentre study. Ann Thorac Surg 2003;76(4):1181-9.

35.Hagl C, Khaladj N, Peterss S, Hoeffler K, Winterhalter M, Karck M, Haverich A. Hypothermic circulatory arrest with and without cold selective antegrade cerebral perfusion: impact on neurological recovery and tissue metabolism in an acute porcine model. Eur J Cardiothorac Surg 2004;26(1):73-80.

36.Dossche KM, Schepens MA, Morshuis WJ, Muysoms FE, Langemeijer JJ, Vermeulen FE. Antegrade selective cerebral perfusion in operations on the proximal thoracic aorta. Ann Thorac Surg 1999;67(6):1904-10.

37.Nappi G, Maresca L, Torella M, Cotrufo M. Body perfusion in surgery of the aortic arch. Tex Heart Inst J 2007;34(1):23-9.

38.Bachet J, Guilmet D, Goudot B, Dreyfus GD, Delentdecker P, Brodaty D, Dubois C. Antegrade cerebral perfusion with cold blood: a 13-year experience. Ann Thorac Surg 1999;67(6):1874-8.

39.Kazui T, Yamashita K, Wahiyama N, Terada H, Bashar AH, Suzuki K, Suzuki T. Aortic arch replacement using selective cerebral perfusion. Ann Thorac Surg 2007;83(2):S796-8.

40.Apostolakis A, Akinosoglou K. The methodologies of hypothermic circulatory arrest and of antegrade and retrograde cerebral perfusion for aortic arch surgery. Ann Thorac Cardiovasc Surg 2008;14(3):138-148.

41.Tian DH, Wan B, Bannon PG, Misfeld M, LeMaire SA, Kazui T, Kouchoukos NT, Elefteriades JA, Bavaria J, Coselli JS, Griepp RB, Mohr FW, Oo A, Svensson LG, Hughes GC, Yan TD. A meta-analysis of deep hypothermic circulatory arrest versus moderate hypothermic circulatory arrest with selective antegrade cerebral perfusion. Ann Cardiothorac Surg 2013;2(2):148-58.