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Anaesthetic management in endovascular total aortic arch repair via needle-based in situ fenestration: a case series of 14 patients

Kui-Rong Wang, Min Gao, Xiao-Hong Wen and Hai-Ying Kong

Abstract

Objective: Endovascular total aortic arch repair (ETAAR) via needle-based in situ fenestration (ISF) is a major challenge for anaesthesiologists because of haemodynamic instability and the risk of cerebral hypoxia. We herein summarise our experience with anaesthetic management of patients who underwent this procedure.

Methods: Fourteen patients who underwent ETAAR via ISF for arch pathologies involving the major supra-arch branches were included. Regional cerebral oxygen saturation was measured to monitor cerebral perfusion. Partial extracorporeal circulation (EC) support from the right common femoral vein to the right axillary artery was introduced to provide cerebral perfusion.

Results: During ISF, vessel rupture occurred in three patients and ventricular fibrillation occurred in one patient. The regional cerebral oxygen saturation significantly decreased during the potential risk period for cerebral ischaemia. Establishment of EC effectively prevented cerebral ischaemia.

Conclusions: During ETAAR, the risks of haemodynamic instability caused by the procedure and vessel rupture during ISF need to be overcome. Partial EC ensured good cerebral protection in our study, and regional cerebral oxygen saturation monitoring may help to reduce the rate of desaturation.

Keywords

Aortic diseases, endovascular total aortic arch repair, general anaesthesia, in situ fenestration, regional cerebral oxygen saturation, extracorporeal circulation

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Department of Anaesthesiology, The First Affiliated Hospital, College of Medicine, Zhejiang University, Hangzhou, Zhejiang Province, P.R. China

Corresponding author:
Hai-Ying Kong, Department of Anaesthesiology, The First Affiliated Hospital, College of Medicine, Zhejiang University, 79 Qingchun Road, Hangzhou, Zhejiang Province 310003, P.R. China.
Email: yahoqi@zju.edu.cn

Introduction

Treatment of pathologies in zones 0 and 1 of the aortic arch (illustrated in Figure 1) is challenging for medical staff because of the complex anatomy of the aortic arch and accompanying diseases.[1,2] Management of these complex diseases involves several procedures, and thoracic endovascular aortic repair has been proposed as a promising alternative treatment for aortic pathologies because of its lower morbidity and mortality rates.[3–8] Endovascular total aortic arch repair (ETAAR) via needle-based in situ fenestration (ISF) is a new technique that has shown fewer complications and has been used to treat aortic pathologies involving the major supra-arch branches.[9,10]

ETAAR stents can also be customised based on imaging data. However, the time needed for such customisation is problematic, especially for patients who have aortic dissection and need immediate surgery. Therefore, ETAAR via needle-based ISF has expanded the indications for ETAAR for aortic arch lesions.

However, anaesthesia for ETAAR poses multiple challenges. ETAAR via needle-based ISF requires sophisticated techniques for stent deployment and ISF, which are associated with the potential risk of vessel rupture. Involvement of the major supra-arch branches can also increase the risk of cerebral ischaemia, and temporary extracorporeal circulation (EC) support may be required to avoid cerebral ischaemia.

This paper presents our experience with anaesthetic management of patients undergoing ETAAR via needle-based ISF, especially with regard to haemodynamic management and maintenance of cerebral perfusion.

Methods

This study was approved by the research ethics committee of the First Affiliated Hospital, College of Medicine, Zhejiang University. Written informed consent was obtained from the patients or their relatives.

We retrospectively analysed the intraoperative and postoperative data of patients

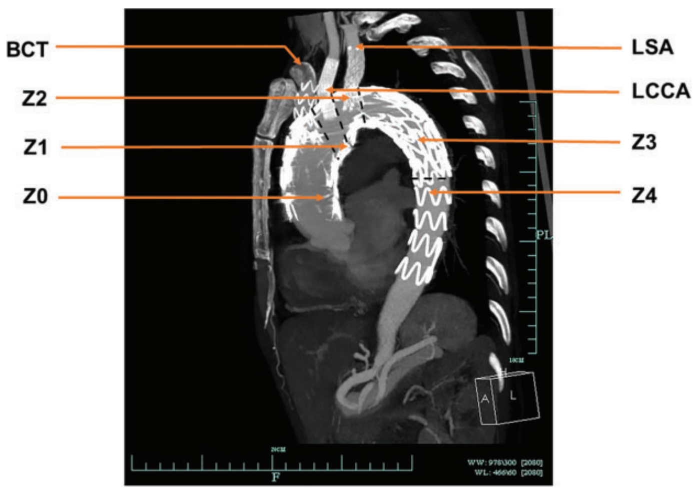

Figure 1. Postoperative computed tomography image of a representative patient. The aortic division (from zone 0 to zone 4, illustrated as Z0 to Z4) and branches of the aortic arch are illustrated. The white part is the aortic stent and the branch stent.
BCT = brachiocephalic trunk, LCCA = left common carotid artery, LSA = left subclavian artery.

who underwent ETAAR for treatment of pathologies involving three supra-arch branches or the proximal seal zone. The inclusion criteria were a retrograde type A aortic dissection, type B aortic dissection, or thoracic aortic aneurysm treated by ETAAR via ISF under general anaesthesia from June 2016 to January 2018. The exclusion criteria were fenestration involving only the left subclavian artery (LSA) or LSA combined with the left common carotid artery (LCCA). Ultimately, 14 patients were included in the analysis.

Invasive arterial pressure monitoring was performed, along with monitoring of central venous pressure via the right internal jugular vein, electrocardiography, end-tidal carbon dioxide, pulse oximetry, body temperature, and regional cerebral oxygen saturation (rSO_2). Right foot dorsal artery or right femoral arterial monitoring was chosen because the coverage of the brachiocephalic trunk (BCT) artery and LSA take-off by the stent graft can influence the blood pressure readings from radial arterial cannulation. The body temperature was maintained above 35.5°C during the procedure except during EC, when it was maintained at 32°C.

Anaesthesia was induced with fentanyl (6 μg/kg), etomidate (0.37 mg/kg), and rocuronium (0.6 mg/kg). Mechanical ventilation was maintained at a tidal volume of 8 mL/kg, and the ventilation frequency was adjusted to maintain an end-tidal carbon dioxide level of 30 to 35 mm Hg. Anaesthesia was maintained with remifentanil (3 μg/kg per hour), propofol (4–5 mg/kg per hour), and sevoflurane (1%–3%). The bispectral index was maintained at approximately 50. Intravenous infusion of lactated Ringer's solution and polygelatin was performed for blood volume replenishment and guided by measurement of the central venous pressure, urine output, and amount of bleeding.

Briefly, the procedure was performed as follows. Angiography of the aorta was performed initially to determine the lesion location, evaluate the range of the affected area, and measure the diameters of the target vessels. Both common carotid arteries and the left brachial artery were exposed to prepare for ISF, and introducers were inserted. After finishing the preparation, a sheath was inserted into the common femoral artery, and two conformable TAG® thoracic endoprostheses (cTAG®; W. L. Gore & Associates, Inc., Flagstaff, AZ, USA) were passed into the ascending and descending aortas. Finally, the supra-arch branches were manually punctured in a retrograde manner using needles, and the branches were revascularised with bridge stents.[9]

The EC from the right common femoral vein (RCFV) to right axillary artery (RAA) was established before the main stent-graft deployment. The blood flow rate was set at 15 to 20 mL/kg per minute, the circuit pressure was maintained at 100 to 150 mmHg, and the perfusion blood temperature was maintained at 32°C. An iced helmet was applied to each patient for additional cerebral protection. The mean arterial pressure (MAP) was controlled to 20% above the preoperative value, haematocrit was maintained at approximately 30%, and partial pressure of carbon dioxide was maintained at 32 to 35 mmHg to ensure cerebral oxygen delivery during the EC.

A stable haemodynamic environment was required, but the environment also needed to adapt to procedure requirements; e.g., permissive hypotension before stent deployment was required to ensure a secure deployment, and a relatively higher MAP was required when the lateral cerebral blood flow was insufficient. Urapidil, nicardipine, and esmolol were administered to maintain permissive hypotension before stent deployment. A 40-μg bolus of phenylephrine was administered to maintain the

Table 1. Baseline characteristics.

Variable	
Sex, male/female	11/3
Age, years	52.3 ± 14.1
Body mass index, kg/m^2	27.7 ± 3.5
Baseline haematocrit, %	33.8 ± 2.7
Baseline mean arterial pressure, mmHg	61.3 ± 7.2
Comorbidities	
Hypertension	11
Renal injury	2
History of coronary artery disease	4
Atherosclerosis	7
Chronic obstructive pulmonary disease	2
Diabetes mellitus	5
Stroke	2
Areas involved by lesions	
Zones 0 + 1 +2 + 3 + 4	9
Zones 1 + 2 + 3 + 4	2
Zones 1 + 2	2
Zone 3	1

Values are expressed as mean ± standard deviation or number.

MAP at 20% above the preoperative blood pressure value from the time of the second cTAG® deployment. If the bolus was required more than three times, continuous administration of norepinephrine was initiated at 1 to 3 µg/kg per minute in accordance with the measured haemodynamic parameters. A heart rate of <50 beats/min was defined as bradycardia, and it was only treated (0.5 mg of atropine, repeated if necessary) if hypotension was simultaneously present.

Haemodynamic and rSO_2 data were obtained from the anaesthesia record at the following time points: before induction (T0), after intubation and cannulation (T1), 1 minute before stent deployment (T2), immediately after aortic endoprosthesis deployment (T3), 10 minutes after aortic endoprosthesis deployment (T4), upon completion of ISF in the LCCA (T5), upon completion of ISF in the BCT (T6), and at the end of the operation (T7). Other variables, such as the EC time and cerebral ischaemia time (from the second cTAG® deployment in the aortic arch to the first balloon dilation in the BCT fenestration), were also recorded. A critical desaturation threshold was regarded as a decrease in the rSO_2 by >20% or a rSO_2 level of <50%. A reduction in rSO_2 to the critical desaturation threshold for more than 1 minute was recorded as cerebral desaturation, and several interventions, including an increase in MAP, were used to restore the baseline rSO_2.

Postoperative data were collected, including the time to extubation and the intensive care unit (ICU) and hospital stay durations. Postoperative complications including pneumonitis, myocardial infarction, heart failure, acute renal injury, and neurological complications were observed during the hospital stay.

Statistical analyses

Patients' data were analysed using SAS release 6.12 (SAS Institute, Cary, NC, USA). Differences in continuous variables were evaluated by one-way analysis of variance followed by the Bonferroni post-hoc test. A P value of <0.05 was considered statistically significant.

Results

Fourteen patients with thoracoabdominal aortic pathologies underwent ETAAR with reconstruction of the major supra-arch branches at our institution. Data on the patients' age, sex, body mass index, indications for ETAAR, and accompanying pathologies are presented in Table 1. The pathologies were classified as follows: five cases of Crawford-type thoracoabdominal aortic aneurysm and nine cases of DeBakey-type aortic dissection (including three cases of Marfan syndrome). The accompanying pathologies included hypertension (11 cases), mild renal insufficiency (two cases), coronary heart disease (four cases), mild myocardial ischaemia (two cases), atherosclerosis (seven cases), chronic obstructive pulmonary disease (two cases), diabetes mellitus (five cases), and stroke (two cases). No dissections involved the coronary or cardiac valve.

The three supra-arch branches were completely reconstructed in 12 patients, while the other 2 patients with a right dominant vertebral artery could not undergo LSA reconstruction because of its tortuous morphology and the sharp angle between the aorta and LSA. The proximal stent grafts were deployed in zone 0. The intraoperative parameters are presented in Table 2.

Significant bradycardia (heart rate of <35 beats/min) was observed in nearly all patients (12/14) when the tight guidewire was introduced to the aortic arch because of the reflex area of the active arch. However, the bradycardia rapidly normalised without treatment, and only three patients needed atropine for additional

Table 2. Intraoperative details.

Variable	
Operative time, minutes	473.5 (350–740)
Cerebral ischaemia time, minutes	88.0 (45–137)
EC time, minutes	96.1 (51–144)
Blood loss, mL	243.6 (120–800)
Total transfusion, mL	2739.3 (2000–4300)
Severe bradycardia	1
Ventricular fibrillation	3
Severe hypotension	13
Desaturation of rSO_2	7
Vessel rupture	2
In situ fenestration	
BCT + LCCA + LSA	12
BCT + LCCA	2

Values are expressed as median (interquartile range) or number. Severe bradycardia was defined as a heart rate of <50 beats/min with the need for atropine treatment to improve hypotension. Cerebral ischaemia time was measured from the second cTAG® deployment in the aortic arch to the first balloon dilation in the LCCA fenestration or BCT fenestration. Severe hypotension was defined as a requirement for continuous administration of norepinephrine after a bolus of phenylephrine. Desaturation was defined as a decrease of >20% in the rSO_2 or an rSO_2 of <50%. EC = extracorporeal circulation, rSO_2 = regional cerebral oxygen saturation, BCT = brachiocephalic trunk, LCCA = left common carotid artery, LSA = left subclavian artery.

hypotension. One patient developed ventricular fibrillation during this period and showed a good outcome after timely treatment with defibrillation and epinephrine.

Significant haemodynamic responses were observed immediately after successful exclusion of the aneurysm, with coverage of the vital cerebral vessel. Esmolol was used to control proximal hypertension in six patients. Most patients (13/14) showed hypotension after EC as evidenced by the requirement for a phenylephrine bolus and continuous norepinephrine administration.

Three cases of vessel rupture occurred in this series: one involving left common iliac artery rupture when retracting the sheath, one involving LSA rupture when performing ISF, and one involving aortic rupture after ETAAR in the ICU. Two of these patients were treated successfully with arterial embolism, and a crossover bypass was additionally performed for the patient with left common iliac artery rupture. However, the third patient died of massive haemorrhage and severe hypotension in the ICU.

The rSO_2 values were recorded during the procedure. The rSO_2 values for both sides significantly decreased immediately after deployment of the aortic endoprosthesis (Figure 2(a)–(d)), and a marked difference was noted between the rSO_2 values on both sides (Figure 2(a)–(d)) after the first establishment of ISF in the LCCA. The bilateral rSO_2 was restored to the baseline level after the establishment of ISF in the BCT. Seven patients showed desaturation during the ISF (Table 2), and all of these patients showed improvement after a series of active treatments such as increasing the MAP. In addition, the rSO_2 returned to $\geq$50% except in two patients with an ischaemia time in the BCT of longer than 1 hour, and the left lateral rSO_2 was 48% to 50% for nearly 10 minutes.

All patients returned to the ICU after ETAAR. One patient died of aortic rupture in the ICU. One patient developed severe hypotension requiring infusion of norepinephrine and blood products because of severe ischaemia of the intestine that

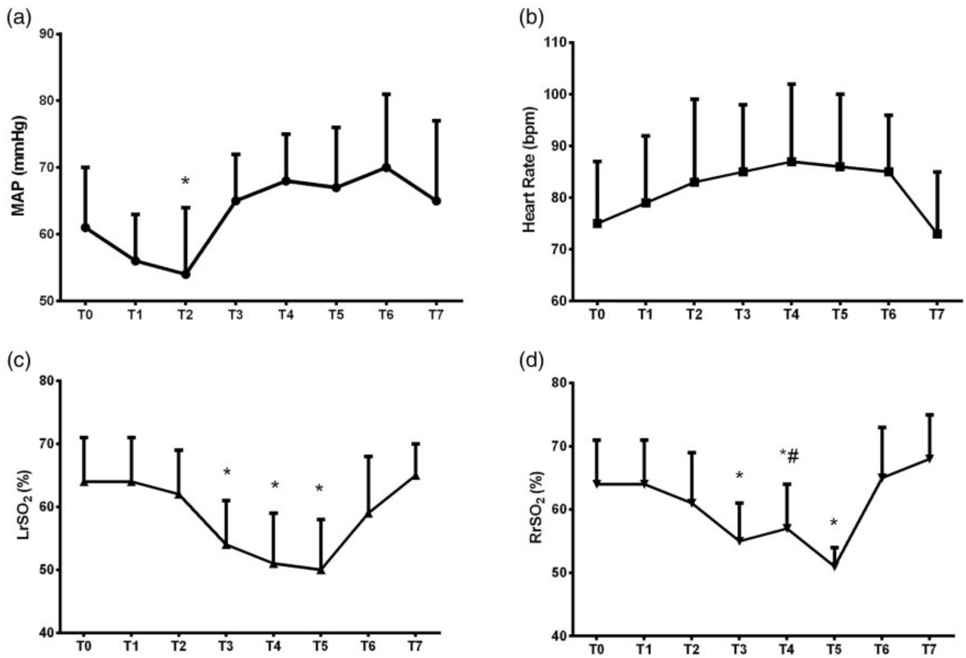

Figure 2. Haemodynamic and rSO_2 data. (a) Mean arterial pressure (MAP). (b) Heart rate (HR). (c) Left rSO_2 value ($LrSO_2$). (d) Right rSO_2 value ($RrSO_2$). rSO_2 = regional cerebral oxygen saturation. All values are expressed as mean $\pm$ standard deviation, with n = 14. *$P < 0.05$, the value vs. baseline value. $^{\#}P < 0.05$ for $LrSO_2$ vs. $RrSO_2$.
Before induction (T0), after intubation and cannulation (T1), 1 minute before stent deployment (T2), immediately after aortic endoprosthesis deployment (T3), 10 minutes after aortic endoprosthesis deployment (T4), complete in situ fenestration (ISF) in the left common carotid artery (T5), complete ISF in the brachiocephalic trunk (T6), and end of the operation (T7).

occurred before the operation for retrograde type A aortic dissection involving the superior mesenteric artery. The patient showed a good outcome after 45 days of medical therapy. The other patients showed a smooth postoperative course, with no in-hospital deaths or serious complication such as heart failure, myocardial infarction, kidney injury, or stroke. Two patients showed postoperative cognitive function impairment during the hospital stay, but their condition quickly normalised after medical therapy.

Discussion

In this case series, careful anaesthesia management allowed implementation of ETAAR via needle-based ISF, which carries risks of complications such as vascular rupture and cerebral ischaemia. This management included target-controlled blood pressure management, establishment of EC, and careful monitoring of key parameters, including rSO_2.

Most of the aortic aneurysms or aortic dissections requiring aortic surgery were associated with complex diseases, including diseases of the cardiovascular, pulmonary, renal, and central nervous systems.[2] They were accompanied by atherosclerosis and hypertension.[2] Adequate evaluation with coronary angiography and a carotid duplex scan was advised to detect stenosis in the cervical arteries and coronary arteries. Patients with moderate and severe stenosis in the carotid arteries and coronary arteries did not undergo needle-based ETAAR because it is associated with a high risk of cardiac and cerebral ischaemia.

Perioperative haemodynamic instability was an important cause of cardiovascular complications in this study. Maintenance of haemodynamic stability was essential during anaesthesia induction, aortic endograft deployment, and ISF. Haemodynamic instability is frequently observed during anaesthesia induction in these patients. Etomidate has been used as a hypnotic drug because of its minimal adverse effects on cardiovascular function, and propofol is not suitable for anaesthetic induction in patients with a complicated medical state.[11,12] A dramatic haemodynamic response can be observed after successful exclusion of the aneurysm with coverage of vital cerebral vessels. Acute partial aortic occlusion can change the afterload and preload with a resultant increase in proximal aortic pressure. Esmolol infusion has been safely used to control proximal hypertension.[2] Hypotension was also observed after EC in the present study, as evidenced by an increased requirement for norepinephrine infusion. The EC alone might affect systemic vascular resistance and catecholamine concentrations depending on the degree of hypothermia, composition of the pump circuit priming fluids, pulsatility of the perfusion, or degree of haemodilution.[13] In addition, the blood flow rate of EC can affect the preload and blood pressure; a high blood flow rate was frequently associated with hypotension.

Another major consideration for ETAAR is the cerebral perfusion during coverage of the aortic arch.[6,9,10] A reduction in the direct or collateral blood supply can increase the risk of inadequate cerebral flow. Higher MAP is required during surgery to improve brain perfusion for patients with preoperative carotid stenosis.[14] The cerebrovascular autoregulation function might be disrupted in patients with atherosclerosis, hypertension, and stroke.[15]

To date, no gold standard for brain function monitoring under general anaesthesia has been established, and local anaesthesia is more favourable for monitoring cerebral perfusion during carotid endarterectomy.[14] However, general anaesthesia was used in our series because of the longer operative time, complicated techniques, and requirement of respiratory system control.[16]

The rSO_2 was used to alert the clinician to inadequate cerebral flow during ETAAR. Several reports have indicated that decreased cerebral oxygen saturation was associated with insufficient cerebral perfusion in cardiac surgery and carotid endarterectomy.[14,15,17] The risk of neurological deterioration significantly increases in patients with an rSO_2 reduction of >20% or an rSO_2 level of <50%.[14,18] Interventions involving increases in the MAP and haematocrit are required to restore the baseline rSO_2 when patients reach a critical desaturation threshold.

The risk of cerebral ischaemia significantly increased in the more complicated cases in our series. The bilateral rSO_2 sharply decreased after coverage of the aortic arch, while the left rSO_2 was significantly lower than that on the right side. This shows the necessity of ISF in the LCCA and the obvious advantageous effect of EC. The temporary EC from the RCFV to RAA was performed quickly after deployment of the stent graft to provide pulsatile flow to the brain and thus avoid unexpected cerebral complications.[9,19] EC in the RAA can provide cerebral perfusion in the left cerebral hemisphere through the circle of Willis. However, perfusion in the left lateral cerebral ventricle was significantly affected as evidenced by the nearly 20% fall in the left rSO_2 when the interval of ischaemia in the BCT exceeded 1 hour. The reasons for this cerebral desaturation are still unclear.

To shorten the cerebral ischaemia period in the LCCA and BCT, several interventions to optimise the oxygen delivery and oxygen demand to the brain can be introduced. Maintaining adequate perfusion pressure and flow during EC has protective effects on the brain.[20,21] The MAP should be kept above the preoperative level during the cerebral ischaemia period because an increased MAP can ensure proper perfusion of the ischaemic area by collateral circulation. Mild hypothermia should be induced during EC with systemic cooling and local head cooling because a body temperature of approximately 32°C is recommended to reduce both mortality and the risk of stroke by reducing oxygen demand.[22,23] The partial pressure of carbon dioxide should be maintained within the normal range during the perioperative period.[24] Hypercapnia is not beneficial to the patients, and hypocapnia may cause cerebral ischaemia. Volatile anaesthetics such as sevoflurane play a significant role in improving outcomes by decreasing the oxygen demand.[25] Methylprednisolone and mannitol may be used to improve brain oedema.[26] Overall, our experience revealed that unilateral EC is sufficiently safe, which is consistent with the findings of some prior reports.[23,27]

This study had some limitations, including its retrospective nature, relatively small sample size, and lack of transoesophageal echocardiography monitoring. Transoesophageal echocardiography will be routinely applied to such patients in our centre in the future because of its ability to display vascular structures and provide real-time haemodynamic information.[28] The anaesthesia methods and drug applications described in this article are based on our own practice norms, and there are other choices in this regard. We are also learning and accumulating experience about the anaesthetic management of this procedure, and we are willing to share these preliminary experiences.

Conclusions

ETAAR via needle-based ISF can be successfully performed for aortic arch pathologies under general anaesthesia with favourable perioperative outcomes. Positive outcomes in these cases can be facilitated by a thorough understanding of the events during ETAAR and the inherent risk factors as well as close attention to haemodynamic stability and brain protection. Partial EC from the RCFV to the RAA was a safe approach and yielded positive outcomes. rSO_2 monitoring may help to reduce the rate of desaturation and improve neurological outcomes.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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ORCID iD

Hai-Ying Kong https://orcid.org/0000-0003-4474-6798

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