Vertebral artery variations in thoracic aortic patients

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Abstract

OBJECTIVES: Arterial variation is common in the vertebral artery, and simple occlusion of the left subclavian artery may result in brain infarction, especially when it terminates in the posterior inferior cerebellar artery (PICA). We report the results of preoperative vertebral artery evaluation by magnetic resonance angiography (MRA) and its impact upon operative strategy.

METHODS: Among the 214 patients who underwent thoracic aortic surgery from 2009 through 2012, 159 patients with preoperative MRA were retrospectively analysed. Patients’ age ranged from 35 to 88 (median 72), 122 were male and 115 had degenerative aneurysms. Prevalence rates of vertebral artery variations and occlusive lesions were reported, together with operative strategies and outcomes.

RESULTS: There were 19 hypoplasia (12%), 10 PICA termination (6%) and 12 occlusive lesion (8%) on the right vertebral artery and 10 hypoplasia (6%), 5 PICA termination (3%), 7 direct arch origin (4%) and 3 occlusive lesion (2%) on the left. Two of the seven arch-originated arteries terminated in the PICA. In aortic arch replacement, these were reconstructed together with the left subclavian artery while hypothermia was maintained. During thoracic endovascular aortic repair with Zone-2 proximal landing, debranching bypass was employed to preserve left subclavian perfusion when there was PICA termination, hypoplasia or occlusive lesion. In 1 patient with hypoplasia between the basilar artery and the left PICA, bypass was added immediately after deployment because radial pressure dropped critically. No brain infarction occurred with this strategy.

CONCLUSIONS: PICA termination and right side hypoplasia/occlusive lesion, where left subclavian perfusion is important for brain protection, is present in ≈ 30%. Left vertebral artery that originated from the arch should be managed with care, because PICA termination is highly prevalent.

Keywords: Vertebral artery • Posterior inferior cerebellar artery • Left subclavian artery occlusion • Magnetic resonance angiography • Brain infarction

INTRODUCTION

Although the importance of the contribution of the left subclavian artery to the brain posterior circulation has been well recognized, its management during thoracic aortic surgery has been controversial. This is true both in the field of brain protection during open surgery [1, 2] and in the situation of left subclavian coverage during thoracic endovascular aortic repair (TEVAR) [3–5]. Previous works have focused mainly upon the development of the circle of Willis in this regard [6]. However, continuity of the Willis circle does not guarantee the blood flow to the cerebellum during left subclavian artery occlusion, when hypoplasia or occlusive lesion is present in the distal vertebral artery. A good example of such a situation is a vertebral artery that terminates in the posterior inferior cerebellar artery (PICA). In addition, vertebral artery hypoplasia has recently been considered to be a predisposing factor for posterior circulation cerebral ischaemic events [7]. Therefore, knowledge of vertebral artery variation may be indispensable in thoracic aortic surgery.

In this study, we evaluated the prevalence of variation or occlusive lesion of the vertebral artery by preoperative magnetic resonance angiography (MRA) and report its impact upon operative strategy and outcomes.

PATIENTS AND METHODS

Among the 214 patients who underwent thoracic aortic surgery from January 2009 through December 2012, 159 patients who underwent preoperative MRA were retrospectively analysed. Patients’ mean age was 71.5 ± 10.1 years (range, 35–88). One hundred and twenty-two (77%) were male, and 37 (23%) were female. The aetiology of aortic disease consisted of 115 degenerative aneurysms, 41 chronic aortic dissection and 3 infected aortic aneurysms. Open surgical repair was performed for 121 patients (aortic root and/or ascending aorta 23, aortic arch 63, descending
aorta 22 and thoracoabdominal aorta 13), and TEVAR for 38 patients.

The prevalence of vertebral artery with hypoplasia, occlusive lesion, direct arch origin and that terminating in the PICA (PICA termination) was evaluated by means of preoperative MRA. The magnetic resonance imaging (MRI) examination was performed using a 1.5-T unit (Signa EXCITE HD 1.5T, GE Healthcare Japan, Tokyo, Japan). Arteries with less than 50% of expected diameter (when compared with neighbouring portion or contralateral side) were considered hypoplastic. The absence of visualization was considered to be aplasia. In this study, hypoplasia and aplasia were grouped together as hypoplasia except, that the aplastic segment was a V4 portion between PICA and the basilar artery (PICA termination). This is because blood flow interruption to the left vertebral artery with aplasia is usually safe except that it terminates in the PICA. Operative strategy according to vertebral artery variations and outcomes were also reported.

This retrospective study was approved by the institutional review board.

Operative strategy according to vertebral artery variations

**Aortic arch replacement.** Our standard technique of aortic arch replacement has previously been reported [8]. Briefly, through a median sternotomy, perfusion cooling was started usually through the ascending aorta, and circulatory arrest was induced and three-vessel selective antegrade cerebral perfusion was initiated when the bladder temperature reached 22–24°C. Distal aortic anastomosis was created first with a four-branched Dacron graft, systemic circulation was resumed through a side branch and rewarming was started. Then proximal aortic anastomosis was completed, and reconstruction of the three arch vessels was performed last.

Because we routinely perfused three arch vessels, special care was required only for the vertebral artery of direct arch origin. In such a case, this branch was simply clamped without perfusion and was connected to a branch graft together with the left subclavian artery as a single button, which was performed before proximal aortic anastomosis while hypothermia was maintained.

**Descending/thoracoabdominal aortic replacement.** Operations were performed through a left thoracotomy. We usually avoided aortic arch cross-clamping but used deep hypothermic circulatory arrest instead, because of the risk of aortogenic brain embolism and retrograde type-A aortic dissection. When the aortic arch cross-clamping under distal aortic perfusion was performed, however, the left subclavian artery was selectively perfused if the left vertebral artery terminated in the PICA.

**Thoracic endovascular aortic repair.** When Zone 0 or 1 proximal landing was scheduled, debranching bypass to the left subclavian artery was performed together with those to the more proximal one or two arch vessels irrespective of the vertebral artery anatomical variation. When only the left subclavian artery was to be covered (Zone 2 landing), however, debranching bypass to the left subclavian artery was preserved to those who had PICA termination, hypoplasia or occlusive lesion on either side of the vertebral artery.

**Aortic arch replacement**

Among the 63 patients who underwent aortic arch replacement, direct arch origin of the left vertebral artery was found in 6, and 2 of them terminated in the PICA. All 6 patients showed uneventful recovery.

**Descending/thoracoabdominal aortic replacement**

Among the 35 patients who underwent descending or thoracoabdominal aortic replacement, only 1 patient underwent aortic arch cross-clamping between the left common carotid and left subclavian artery. This patient had a left vertebral artery that terminated in the PICA. Therefore, the left subclavian artery was selectively perfused, and the patient showed uneventful recovery.

**Thoracic endovascular aortic repair**

Among the 11 patients who underwent TEVAR with Zone 0–2 proximal landing, 3 had vertebral artery variation. Five of the 11 underwent Zone 0 or 1 landing, and therefore underwent bypass grafting to the left subclavian artery. One of them had hypoplastic right vertebral artery with stenosis at the junction with the basilar artery. Among the remaining 6 patients who underwent Zone 2 proximal landing, 3 underwent axillo-axillary bypass grafting. In 2 of them, prophylactic bypass was created immediately before stent-graft deployment. One of them had left vertebral artery that terminated in the PICA, and the other had arteriovenous shunt on the left forearm for haemodialysis. Because variation or occlusive lesion was not found in the vertebral arteries in the latter patient, the left subclavian artery was ligated at the proximal end of the bypass graft anastomosis. In the remaining patient, bypass was added immediately after stent-graft deployment because left radial arterial pressure dropped critically. In this patient, the vertebral artery was hypoplastic but continuous between the basilar artery and the left PICA (Fig. 3), and therefore, we prepared but did not prophylactically perform bypass grafting. All 3 patients with variation recovered uneventfully.

**Clinical outcomes in the entire cohort**

Among the 159 patients, no patient died within 30 days of surgery and 2 patients (1.3%) died during hospital stay. The causes of deaths were aspiration pneumonia in an octogenarian patient with severe COPD and fulminant hepatitis due to immune suppression therapy for pre-existing idiopathic thrombocytopenic purpura in another. Intraoperative stroke occurred in 1 patient.
and paraparesis in 1. The former occurred in a patient with multiple histories of stroke who underwent Zone-0 TEVAR, and was due to a haemodynamic factor in the right middle cerebral artery territory. Paraparesis occurred in a patient with Zone-3 TEVAR, which seemed to result from an embolic event. An additional 3 patients who underwent aortic arch replacement suffered from variable degrees of neurocognitive dysfunction.

DISCUSSION

Arterial variation is common in the vertebral artery. Direct arch origin of the left vertebral artery is the second most common anatomical variation of the aortic arch. In the clinical studies using computed tomography in >1000 subjects, the prevalence of this variation was 4.1–6.6% [9-11]. On the other hand, the reported prevalence of hypoplastic vertebral artery is highly variable according to the imaging modality and definition. In the previous studies using colour Doppler ultrasonography, hypoplasia was defined as <2–3 mm or 50%, and its prevalence in the subjects without cerebrovascular disease ranged from 1.9 to 11.6%, the right side being twice more common than the left [7]. An MRI study reported that the prevalence of hypoplastic vertebral artery in patients with neck pain was 44%, with moderate or severe hypoplasia in 44% of them (19% of total cohort), although the method to grade severity was subjective [12]. In this study, hypoplasia was more common in females and 81% was on the right side.

The prevalence of vertebral arteries that ended in the PICA was reported to be 4.6% by MRA in asymptomatic subjects [13], 4.4% by 64-slice computed tomography angiography [14] and 5.8 and 6.3% by ultrasonography and angiography, respectively, in patients with cerebrovascular disease [15]. This consistency suggests the accuracy of MRA in detecting PICA termination, while it has an advantage of being free of contrast medium adverse reaction and interexaminer variability, which may be seen in ultrasonography. In the MRA report, additional 5.1% had hypoplasia between the vertebral and basilar artery that was not visualized by standard MRA but could be detected by a more sensitive technique (basiparallel anatomical scanning designed for recognition of outer contour of the artery). These data seem consistent with the result of the current study and suggest the clinical importance of preoperative vertebral artery evaluation.

Vertebral artery hypoplasia has recently been considered to be a predisposing factor for posterior circulation cerebral ischaemic

![Figure 1: Magnetic resonance angiography showing hypoplasia (A), posterior inferior cerebellar artery termination (B) and occlusive lesion (C) on the right vertebral artery.](image1)

![Figure 2: Magnetic resonance angiography showing hypoplasia (A), posterior inferior cerebellar artery termination (B) direct arch origin (C) and occlusive lesion (D) on the left vertebral artery.](image2)
events [7]. It has been shown that flow volume and velocities are decreased in a hypoplastic vertebral artery, which is presumed to be a cause of susceptibility to prothrombotic or atherosclerotic processes. During thoracic aortic surgery, temporary or permanent occlusion of the left subclavian artery may therefore result in significant flow reduction in the posterior circulation of the brain, when the right vertebral artery is hypoplastic or it ends in the PICA. When the left side terminates in the PICA, temporary or permanent occlusion of the left subclavian artery may result in critical cerebellar ischaemia. Such variations were present in ≏20% of thoracic aortic patients in the current study, which seems comparable with that reported by Sugiura et al. [16]. Combined with additional 10% of patients who had acquired occlusive lesion, simple occlusion of the left subclavian artery may not be safe in up to 30% of our patients.

Such information is of particular importance when TEVAR with Zone 0–2 proximal landing is scheduled. The necessity of left subclavian artery revascularization has been a matter of debate, but recent review articles recommend prophylactic revascularization in elective cases and in patients with high-risk anatomy, although the level of evidence is low [3–5]. The present study is focused mainly upon brain circulation and not on the spinal cord or arm complication, but it still shows that ≏30% of patients had high-risk anatomy. Therefore, we do not recommend subclavian coverage without revascularization in the absence of preoperative information during TEVAR.

Similar consideration may be possible for open descending aortic repair with aortic arch cross-clamping under normothermia. Although blood flow interruption to the left subclavian artery is transient in this setting, it may exceed the safe limit of brain ischaemia. Because collateral blood flow may not be enough in the presence of high-risk anatomy, we recommend selective subclavian artery perfusion, as reported by Tsuchida et al. [17], if aortic arch cross-clamping is mandatory.

During aortic arch replacement under selective antegrade cerebral perfusion, on the other hand, omitting left subclavian artery perfusion or even unilateral perfusion may well be tolerated, depending upon the brain temperature and duration of blood flow interruption [1, 2]. We use three-vessel perfusion because we do not maintain hypothermia during selective antegrade cerebral perfusion but start to rewarm the patients after distal aortic anastomosis, and we reconstruct the three arch vessels finally after the proximal aortic anastomosis is completed. In the beginning of our experience, we used three-vessel perfusion selectively in patients with high-risk anatomy under careful monitoring [18]. However, we now use three-vessel perfusion in every patient because nothing is different between two- and three-vessel perfusion in the operative field.

Although Papantchev et al. [6] reported that two-vessel perfusion is enough for most patients from a cadaver study of the continuity of the circle of Willis, they neglected vertebral artery variations and their contribution to the brain posterior circulation. Nowadays, many surgeons are using higher temperature during aortic arch reconstruction with or without preoperative evaluation of cerebral arteries. In this setting, left subclavian perfusion may be more important for brain protection [1]. In addition, circulatory arrest at a higher temperature carries an increased risk of spinal cord injury, and the importance of the vertebral arteries for spinal cord blood supply has been well documented [1]. Furthermore, many European centres are now using the frozen elephant trunk technique for aortic arch surgery, which is associated with high incidence of ischaemic spinal cord injury, especially when it is applied to degenerative aneurysms with severe atherosclerosis and the trunk is inserted deep into the descending aorta [19]. Because left subclavian perfusion may reduce the risk of paraplegia when selective antegrade cerebral perfusion is used [20], management of the left subclavian artery during selective antegrade cerebral perfusion should also be re-evaluated from this viewpoint.

Figure 3: Magnetic resonance angiography of the patient who underwent axillo-axillary bypass grafting immediately after stent-graft deployment. Note that the vertebral artery was hypoplastic but continuous between the basilar artery and the left posterior inferior cerebellar artery.
Another important finding of the present study is that two of the seven vertebral arteries that directly originated from the arch ended in the PICA. Although such an association has not been reported, this finding may have a clinical significance because the small size of the arch-originated vertebral artery usually precludes selective perfusion. Thus, they should be managed with special care to avoid cerebellar infarction, and we reconstructed them while hypothermia was maintained.

In conclusion, PICA termination, hypoplasia or occlusive lesion on either side of the vertebral arteries, which is high risk for posterior circulation brain ischaemia, is present in ~30% of thoracic aortic patients. We, therefore, recommend routine preoperative evaluation and left subclavian bypass in Zone 2 TEVAR when such a high-risk anatomy is detected.

Conflict of interest: none declared.

REFERENCES


APPENDIX. CONFERENCE DISCUSSION

Dr V. Papantchev (Sofia, Bulgaria): The authors present excellent results, with only 1.3% in-hospital mortality and a low number of neurological complications. The work of Dr Ohkura and colleagues once again supports the superiority of bilateral selective cerebral perfusion and shows the importance of perfusing the left subclavian artery. It also supports the need for meticulous preoperative examination of the brain vasculature, including Willis circle and verteobasilar system for identifying the patients with high-risk anatomy and planning of the intervention. I think that this is especially important at the present time because of this tendency for using higher temperature during selective cerebral perfusion, and, furthermore, it is well known that intraoperative monitoring with near infrared spectroscopy (NIRS) is not capable of identifying perfusion problems in the brain stem and the cerebellum.

I have a few questions. My first question is, since 1.5 tesla MRI is not superior to CT angio concerning the visualization of blood vessels, and usually MRI is not widely available, why did you prefer MRI over CT angio?

Dr Ohkura: For intracranial examination we perform MRI, and for the orifice of arch vessels and thoracic vertebral artery we always perform a CT scan.

Dr Papantchev: It is kind of your institutional protocol to perform MRI? Dr N. Shiiya (Kumamoto, Japan): I am a corresponding author and I will answer your questions instead of Dr Ohkura. When we perform this CT angio we need contrast medium, and we had many elderly patients and patients with chronic kidney disease. So we prefer to avoid using contrast medium in such patients. That is one reason.

Dr Papantchev: My second question is, can you comment on your criteria for defining hypoplastic vessels? Because in your manuscript you state that the criterion for defining hypoplastic vessels was “a vessel with a diameter half the diameter on the contralateral side”, which is quite subjective to me. Can you comment on this, your criteria for hypoplastic vessels, why you choose this criterion and not some size, for example?

Dr Shiiya: The diagnostic criteria are subjective, but it’s performed by the radiologist, who doesn’t know the exact aortic pathology and the aortic strategy. It’s subjective, but it’s a usual way.

Dr Papantchev: But choosing a subjective criteria could jeopardize such a beautiful study as this one. Since most of your patients were suffering from chronic degenerative aneurysms or chronic dissections, did you have any observation on extracranial collaterals, which is not a subject of your study, I understand this, but did you have any observation on this?

Dr Shiiya: In an MRI study it is very difficult to make any measure of the extracranial collaterals. So I don’t have an answer for you.

Dr Papantchev: And my final question is, you mentioned in your manuscript that you had three patients having various degrees of neurocognitive disorders. Did you perform any specific and precise preoperative or postoperative estimation of the neurological outcome in respect to cognitive, affective or personality changes, for example, tests like the Thematic Apperception Test (TAT), the Minnesota Multiphasic Personality Inventory, also known as MMPI, Hospital Anxiety and Depression scale? Did you perform any of these specific tests, or did you have other criteria?

Dr Shiiya: We don’t have any control examination of neurocognitive function. We can’t say that the patients have postoperative cognitive loss. It’s a weakness of this study. But the three patients who had postoperative neurocognitive dysfunction actually had a postoperative delirium and subsequently they seemed somewhat strange from the surgeon’s view, so we considered that they actually had neurocognitive dysfunction.

Dr Papantchev: It is a good idea for further examination.