Preoperative demonstration of the Adamkiewicz artery by magnetic resonance angiography in patients with descending or thoracoabdominal aortic aneurysms

Naoaki Yamada\textsuperscript{a}, Yutaka Okita\textsuperscript{b,}\textsuperscript{*}, Kenji Minatoya\textsuperscript{b}, Osamu Tagusari\textsuperscript{b}, Motomi Ando\textsuperscript{b}, Makoto Takamiya\textsuperscript{a}, Soichiro Kitamura\textsuperscript{b}

\textsuperscript{a}Department of Radiology, National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan
\textsuperscript{b}Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan

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Abstract

Objective: Investigating the possibility of magnetic resonance angiography (MRA) to visualize the Adamkiewicz artery of as a preoperative study of thoracic aortic aneurysms.

Methods: From February 1998 to March 1999, 26 consecutive patients who had aneurysms of the thoracoabdominal or descending aorta underwent preoperative MRA to visualize the Adamkiewicz artery. Mean age was 60.5 ± 11.5 years. Fifteen patients had non-dissecting aneurysm and 11 had aortic dissections. Nineteen patients underwent replacement of the aneurysms, four patients underwent endovascular stent-graft repair, and three patients were discharged without treatment of aneurysm. MRA was performed on a 1.5-T system (Magnetom, Siemens) and data acquisition was repeated two times following injection of gadolinium-DTPA. Source images were reconstructed with multiplanar reconstruction and maximum intensity projection. Criteria for the Adamkiewicz artery were that the artery ascends from the dorsal branch of the intercostal or lumbar artery to the anterior mid-sagittal surface of the spinal cord in the early phase.

Results: The Adamkiewicz arteries were demonstrated in 18 patients (69%). These arteries were originated from the left intercostal or lumbar arteries in 13 (72.2%) patients and from the right in 5 (27.8%) and from the Th8 branch in three, Th9 in seven, Th10 in two, Th11 in four, and L1 in two. All patients had graft replacement of the aorta using a partial bypass. All intercostal or lumber arteries, which were visualized as the origin of the Adamkiewicz artery, were reattached to the grafts. No spinal cord injury occurred.

Conclusion: Preoperative detection the Adamkiewicz artery was possible by MRA and was very useful to reduce the incidence of ischemic injury of the spinal cord during surgery of the thoracoabdominal or descending aorta.

Keywords: Magnetic resonance; Vascular studies; Magnetic resonance angiography; Contrast enhancement; Spinal cord ischemia; Aneurysm; Surgery; Arteries; Spinal; Aorta; Aneurysm

1. Introduction

Postoperative neurological deficit is a serious and unpredictable complication of surgical and endovascular stent-graft repair of thoracic descending aortic aneurysms. The major cause of the deficit is considered to be spinal cord ischemia during and after the procedures. In the thoracolumbar region, it is known that the great anterior medullary artery (the artery of Adamkiewicz, arteria radicularis magna: ARM) is the dominant feeder of the spinal cord. Many surgical reports stressed the importance of reattachment of the intercostal artery related to the ARM [1–6].

To avoid occlusion of the ARM, it would be useful to know the level of the intercostal artery that originates the ARM before the procedures. To visualize the ARM however, it has been required to perform arteriography with selective catheterization of intercostal and lumbar arteries. The selective arteriography is considered to be time consuming, difficult and hazardous in cases with aortic aneurysms, and therefore, preoperative evaluation of the ARM has been uncommon [1]. Recently, magnetic resonance angiography (MRA), that is non-invasive, has been developed [7–10]. In aortic and major peripheral arterial studies, usefulness of contrast MRA has been established. Up to now however, no report of MRA of the spinal artery has been made. This study would help us in planning of surgical and endovascular stent-graft repair of thoracic aortic aneurysms to prevent neurological deficit.
2. Materials and methods

Between May 1998 and March 1999, 26 patients with thoracic aortic aneurysm underwent contrast MRA to visualize the artery of Adamkiewicz (ARM). Six of the 26 patients had undergone previous graft surgery of descending or abdominal aortic aneurysms. The age of the patients ranged from 29 to 83 years (60.5 ± 11.5) with a male to female ratio of 19:7. Five patients with dissecting aneurysm had Marfan syndrome. Nineteen patients underwent open surgery, four patients underwent endovascular stent-graft repair, and three patients discharged without a treatment of descending aortic aneurysm because of malignant neoplasm, poor cardiac function, and priority of the ascending aortic aneurysm to be treated.

2.1. Imaging protocol

Contrast MRA was performed on a 1.5-T machine (MAGNETOM Vision, Siemens Medical Systems, Erlangen, Germany). First, localization imaging was performed with a wide field of view in coronal, sagittal, and transverse orientations (Fig. 1). Second, a test-bolus of 1 ml of gadolinium dimegulumine (Gd-DTPA; MAGNEVIST, Schering, Berlin, Germany) was injected at the same rate as that in contrast MRA to determine time to start imaging sequence. Test imaging was performed every 1 s on a transverse section at the level of diaphragm by using inversion-recovery turbo fast-low-angle-shot (turbo-FLASH) sequence. Third, a mask imaging was performed by using the same parameters as the three-dimensional contrast imaging described below. Finally, contrast imaging was repeated two times contiguously following injection of 0.3 mmol/kg body weight of gadolinium-DTPA to obtain early and late phase images. Starting delay of imaging sequence was set near transit time of the test bolus between the injection site and the descending aorta at the diaphragm level [11].

A power injector (SPECTR IS; Medrad, Pittsburgh, PA) which was connected to the antecubital vein regulated the injection rate to continue injection of Gd-DTPA for a time of 2/3±4/5 of data acquisition time. The resulting injection rate ranged from 0.8 to 2.0 ml/s (mean 1.3).

The imaging sequence was a three-dimensional FLASH that had the highest resolution among sequences available for contrast MRA on the machine used in this study. The resulting pixel size was approximately 0.9 × 0.5 mm², and slice thickness was 1.2 mm with reconstruction interval of 0.6 mm after zero-filled interpolation [10]. Imaging volume

Fig. 1. Lateral view of the thoracic aorta (left). A horizontal window of the Th12 intercostal artery (right) demonstrated a patent intercostal artery from the aorta, dorsal branch, the radiculomedullary artery, anterior ramus, and posterior ramus.
covered the level from T6 or T7 to L2 or L3 in cranio-caudal direction, and the vertebral body in left-right direction. Patients were required to breathe calmly and not to move the body during imaging.

2.2. Data processing

Source images were processed with multi-planer reconstruction (MPR) with 0.6-mm contiguous sections covering the spinal cord. In the early and the late phase images exactly the same MPR sections were used, and the two MPR images were compared with each other on the same display window. If a vessel was detected to run from the dorsal branch of the intercostal artery to the anterior surface of the spinal cord, double oblique MPR was performed to track the vessel in a single section as long as possible. Maximum intensity projection (MIP) of small volume was reconstructed from MPR images. Subtraction was performed between the early phase and the mask images.

2.3. Criteria of the artery of Adamkiewicz and the anterior spinal artery

Diagnostic criteria of the ASA were, (1) placed on the anterior midsagittal surface of the spinal cord and (2) signal intensity in early phase is not lower than that in late phase. Criteria of the AKA were (1) continuous to the ASA with the hairpin turn on early phase image, (2) the vessel goes to the anterior midsagittal surface of the spinal cord from the radicular-medullary artery that originates from the dorsal branch of the intercostal or lumbar artery and (3) signal intensity in early phase is not lower than that in late phase.

2.4. Treatment

Nineteen patients underwent replacement of the aneurysm of the descending or thoracoabdominal aorta using a partial cardiopulmonary bypass under mild hypothermia (nasopharyngeal temperature 32–34°C). After left thoracic cavity and/or left retroperitoneal space was entered, cannulation into the left femoral artery and femoral vein was used in all patients. By transcranial electrical stimulation, motor evoked potentials form the lower leg muscles were monitored during aortic procedures. Reconstruction of a pair of the intercostal arteries was performed using an 8-mm graft interposition in 15 patients and using an island cuff technique in four patients. The reconstructed intercostal arteries were target arteries which were identified as giving a branch to the ARM by preoperative MRA and arteries which were above and below the target one. Numbers of reconstructed intercostal arteries ranged from one to five pairs and averaged in 3.8 ± 2.5 pairs in each patient.

Table 1
Summary of study results

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Age/sex</th>
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MRA, magnetic resonance angiography; DSA, digital subtraction angiography; ARM, artery of Adamkiewicz; ICA, intercostal artery; ASA, anterior spinal vein; AMV, anterior medullary vein; DA, aortic dissection; A, Stanford type A; B, Stanford type B; TAA, non-dissecting thoracic aneurysm; o.v., out of view.
Four patients underwent endovascular stent-grafting for exclusion of the aneurysms. An Inoue-stent-graft was inserted from the femoral artery and placed at the appropriate position. The graft was deployed and attached to the aortic wall firmly using an intra-aortic balloon pump catheter. Whole procedures were performed under local analgesia. When the graft was considered to occlude the orifices of the targeted intercostal arteries, our plan was to ask the patient to move his leg after 30 min of graft deployment. If there was any signs and symptoms of cord ischemia, such as paraplegia, paraparesis, or numbness of the lower legs, the lower end of the stented graft was moved upward to clear the orifice of the intercostal arteries. Fortunately, no patients required such revision of the graft.

3. Results

There was no mortality and no spinal cord injury in this subset of the patients.

Table 1 summarizes the results of this study. MRA demonstrated the artery of Adamkiewicz (ARM) in 18 of 26 (69%) patients. Segmental levels of the intercostal or lumbar artery that originated the ARM ranged from T8 to L1. The ARM originated from the left side in 13 (72%), and between T9 and T12 in 13 (72%) of the 18 patients. Origin of ARM related intercostal artery from the aorta was confirmed to be patent in five patients and occluded in four patients. Anastomosis between occluded intercostal arteries and the near patent intercostal arteries was visualized occasionally. In the remaining nine patients, the origin was out of view because of narrow slab thickness. The ASA caudal to junction with ARM was identified in 13 patients. The cranial portion of the ASA to the junction was not identified in any patient. The great anterior medullary vein was visualized in 17 patients, and the junction with the anterior median vein was placed between T10 and T12. Selective DSA demonstrated the ARM at the level and side predicted by MRA in three patients (Figs. 2 and 3).

The anterior medullary vein mimicked the ARM in the Adamkiewicz zone in 17 patients (Table 1). The vein, however, descended in a long segment, and was not continuous to the dorsal branch of the intercostal or lumbar artery and the signal intensity increased in the late phase. The

Fig. 2. Case 11, a 69-year-old male with dissecting aneurysm (DeBakey type III). This patient underwent endovascular stent-graft treatment after MRA. Just before insertion of a stent, selective DSA was performed to confirm the ARM and the related intercostal artery. The artery of Adamkiewicz (ARM) ascends from the dorsal branch of the left T8 intercostal artery to midsagittal anterior surface of the cord (left). The anterior spinal artery is continuous to the ARM with hairpin turn. Selective DSA (right) demonstrates the ARM originating from the left T8 intercostal artery, and the retrocorporeal anastomosis.
anterior medullary vein left the anterior median vein from segments of T10 to T12 (Fig. 4).

MIP images from subtracted images (early phase-mask) was used to visualize the aorta and the intercostal and lumbar arteries in a wide view (Fig. 5). On the subtracted MIP images, veins were weakly or little enhanced. Collateral arteries if present were well visualized. Patency of intercostal or lumbar artery at the origin from the aorta was, however, not confirmed in one half of the ARM identified patients because slab thickness used in this study was narrow.

4. Discussion

In the thoracolumbar region, it is known that there is almost always a dominant anterior medullary artery that is called the artery of Adamkiewicz (ARM). In anatomical studies, the ARM was reported to originate from the left side in 68% (12) to 73% (13) and between T9 and T12 in 62% (13), 68% (12), and 75% (14). The results of this study coincided with these reports.

4.1. Differentiation of artery from vein

A larger vessel can have a higher signal intensity than a smaller vessel due to the partial volume effect. Internal diameter of the anterior spinal artery (ASA) and the artery of Adamkiewicz (ARM) in the thoracolumbar region is 0.5–1.2 mm [12–14]. The experimental results showed that vessels not larger than 0.5 mm in diameter are not visualized with the sequence used in this study. Therefore, all the other spinal arteries than ARM and ASA (for example, the posterior medullary artery, the central artery, additional anterior medullary artery) are believed not to have been visualized. Cranial portion of the anterior spinal artery to the junction with the ARM is usually smaller in diameter than the caudal portion [15].

Bowen et al. tried to visualize intradural vessels with contrast MRA, and almost all the vessels visualized were veins [16]. Close observation is essential to differentiate the artery of Adamkiewicz (ARM) from the anterior medullary vein. The most reliable criterion of the ARM would be continuity of the vessel with the intercostal or lumbar artery in the early phase. The second most reliable criterion would be decrease of signal intensity in the late phase. There are several adjuncts for the differentiation. Segmental level where the great anterior medullary vein leaves the anterior median vein is lower than the level where ARM joins the ASA. In this study, almost all of the anterior medullary vein left the anterior median vein between T10 and T12. Some authors reported that the great anterior medullary vein leaves usually from segments of T11 to L3 [17]. The junction of the anterior medullary vein and the anterior median vein is reported to have typically a coat-hook configuration.

Fig. 3. Case 10. The ARM from the left Th9 intercostal artery (right). Selective DSA of the left Th10 also demonstrated a hairpin curve (right).
that is more dull than the hair-pin turn configuration [18]. However, the configuration is variable, and can mimic the hair-pin turn frequently (Fig. 4).

It must be taken into account that the anterior median vein parallels the anterior spinal artery, lying slightly deeper and to the side of the artery in the median sulcus [17,18]. Although the anterior median vein is usually more tortuous than the ASA, the ASA also can be tortuous to some extent. Because of limited spatial resolution used in this study, morphological differentiation between the ASA and the anterior median vein seems to be difficult.

4.2. Clinical value of spinal MRA

Crawford reported that patients who underwent surgical repair of descending and abdominal aortic aneurysms suffered from neurological deficit especially when long segmental aneurysm was repaired [19]. Recently, various surgical adjuncts to protect the spinal cord have been developed [1–4,20,21], but still many patients suffer from paraplegia or paraparesis in various incidences depending upon study groups. Permanent spinal cord complications after replacement of the thoracic descending aorta have ranged from 1 to 5% [4]. Although some authors suggested that spinal cord blood supply is unlikely to depend on a single artery of Adamkiewicz [21], most other authors described the importance of preserving arterial supply in the Adamkiewicz zone [1–4].

In endovascular stent-graft repair, paraplegia occurred in 3.7% (3/81) for thoracic aortic aneurysm [5], and in 5.6% (1/18) for combined open surgery of abdominal aortic aneurysm and endovascular stent-graft repair of thoracic aortic aneurysm [6]. To prevent ischemic injury of the spinal cord, excess distal stent-graft length should be avoided if an intercostal artery that may be related with the ARM is noted before the procedure [6].

In this MRA study, origin of ARM related intercostal artery from the aorta was confirmed to be patent or occluded in only nine patients. However, MRA, although incomplete, provide a great information about patent intercostal artery and collateral vessels. Information about segmental level of the ARM itself is useful because surgical repair can be performed with intensive care to revascularize the intercostal and lumbar arteries at or near the level of the ARM. Stent-graft can be planned and placed carefully to avoid occluding ARM related intercostal or lumbar artery.
Selective DSA to confirm the ARM, if necessary, can be performed less invasively in a limited number of intercostal or lumbar arteries on the basis of MRA findings.

In summary, this study demonstrated the capability of contrast MRA to visualize the artery of Adamkiewicz. Optimization of gadolinium injection protocol and improvement of imaging sequence to obtain a higher resolution and contrast should be continued.

References


Fig. 5. The ARM from the left Th10 (left). Subtracted images of the ARM (middle). The anterior medullary vein (right).


Appendix A. Conference discussion

**Dr M. Turina (Zurich, Switzerland):** In 70% of patients you could demonstrate the artery and in 30% you did not, and still you didn’t experience any incidence of paraplegia. What changes have you made in the other 30% of the patients where the artery was not demonstrated?

Are you really depending on the demonstration of Adamkiewicz artery or are you depending on the demonstration of the collaterals, which you didn’t touch upon? We all know that some of the people will tolerate the obstruction of the Adamkiewicz artery without paraplegia, and this is due to the extensive collaterals. Did you try to demonstrate the collaterals in your MRA examination?

**Dr Okita:** In 30% of the patients we could not demonstrate the Adamkiewicz artery by MRA; especially in the chronic aortic dissection, it is very difficult to demonstrate because the flow pattern of the dissection and the true lumen is very different and sometimes very slow. And a technical problem is that the gadolinium is very difficult to visualize the spinal artery.

As for surgery, yes, we rely, in some part, on this information. But usually our surgery is that we reconstruct all intercostal arteries between Th8 and the Th12. But rarely does the Th5 or L3 supply the very critical intercostal lumbar artery to the spinal cord. We haven’t had such cases, but there exist some reports in the literature. So this is our surgical principle. And remarkably, a third of the patients had the occluded intercostal artery, above and below which is thought to be a branching Adamkiewicz artery and usually the intercostal artery, above and below the Adamkiewicz artery was giving off rich intercostal collateral pathways. So we tried to reconstruct the target one, and additionally above and below, very, very meticulously during surgery.