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MR Angiography for Detecting the Artery of Adamkiewicz and Its Branching Level from the Aorta

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Purpose: We evaluated the efficacy of magnetic resonance angiography (MRA) for detecting the artery of Adamkiewicz (AKA) and the vertebral level of its feeding arteries branching from the aorta.

Materials and Methods: Eighty-two patients (67 men, 15 women; aged 34 to 86 years, mean age 68.6 years) with thoracic descending and thoracoabdominal aortic lesions (aneurysm in 55, dissection in 25, coarctation in 2) underwent MRA to detect AKA. MRA was performed using 6-phase, dynamic-enhanced, 3-dimensional, fast spoiled gradient recalled acquisition in steady state (GRASS) on a 1.5-tesla (T) system, with double-dose bolus contrast injection. The vertebral levels of AKA branching and the AKA feeder artery branching from the aorta were determined.

Results: The AKA was detected in 67 patients (81.7%). Branching of AKA occurred at levels T7 to T12 on the left side (n = 52) and on the right (n = 15). Vascular continuity from the aorta to the anterior spinal artery was demonstrated in 55 patients (67.1%). Comparing the vertebral level of arterial branching from the aorta to that of the AKA at the intervertebral foramen, the AKA branched at the same vertebral level in 44 patients (80.0%), one vertebral level above/below in 10 (18.2%), and 2 vertebral levels above in one (1.8%).

Conclusion: MRA can be useful in the preoperative work-up of patients with thoracoabdominal aortic lesions to localize AKA and the segmental trajectories of vessels supplying blood to the AKA.

Keywords: *aortic aneurysm, aortic dissection, artery of Adamkiewicz, MR angiography (MRA), surgery*

Introduction

Postoperative paraplegia/paraparesis is a serious complication of reconstructive surgery for thoracic descending and thoracoabdominal aortic lesions, i.e., aneurysm, dissection, or coarctation. The major cause of spinal complication is thought to be spinal cord ischemia during and/or after the procedure. Owing to advances in anesthetic and surgical techniques, the frequency of severe neurologic complications has declined, but the rate of postoperative spinal complication remains high, in the range of 5 to 10%.¹⁻³ Maintaining blood supply to

the spinal cord is thought to be a key factor in reducing the risk of spinal complications. Recent studies have reported that the rate of spinal cord ischemia was significantly decreased in patients who underwent successful preoperative identification of the artery of Adamkiewicz (also known as the great anterior radiculomedullary artery and the dominant arterial feeder of the spinal cord) compared to patients in whom this artery was not identified.^{4,5}

Greenberg's group reported on neurologic deficit caused by spinal cord ischemia in 3 of 25 patients (12%) undergoing endovascular thoracoabdominal aneurysm repair, with long-segment thoracic aortic coverage found to be a significant risk factor in predicting clinically evident spinal cord ischemia.⁶

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It has been suggested that reattachment of the intercostal arteries during repair of the descending thoracic or thoracoabdominal aorta could minimize the occurrence of such complications.⁷ Before reconstructive aortic surgery, knowledge of the branching level of the intercostal artery from which the artery of Adamkiewicz originates would be useful in preventing neurologic complications. Therefore, we prospectively evaluated detection of the artery of Adamkiewicz⁷ by MR angiography (MRA) that included an additional scan that visualized the aorta to determine the vertebral level of feeding arteries branching off from the aorta and the branching trajectory to the anterior spinal artery.

Materials and Methods

Patient population

This study was approved by the institutional review board. All patients who participated provided written informed consent.

From March 2006 through May 2008, 82 patients (67 men, 15 women; aged 34 to 86 years, mean age, 68.6 years) underwent MRA to detect the artery of Adamkiewicz. Patients included 55 with thoracoabdominal aortic aneurysm (Crawford type I, 26 patients; II, 3 patients; III, 3 patients; IV, 2 patients; and arch, 21 patients), 25 with thoracoabdominal aortic dissection (DeBakey type I, 3 patients; II, 0 patients; IIIa, 5 patients; and IIIb, 17 patients), and 2 with coarctation.

MRA protocol

MRA was performed with a 1.5T system (Signa Infinity Excite; GE Medical Systems, Milwaukee, WI, USA). Because reconstruction of the radiculomedullary artery is considered an essential part of aortic graft implantation at our institution, a 24-cm field of view (FOV) from above the second lumbar (L2) vertebral level was examined in each patient. We used the L5 vertebra and the twelfth thoracic (T12) rib to localize the L2 vertebra as the lower boundary of the FOV on a positioning scan. As in the previously reported protocol,⁷ a dynamic study was performed by enhanced, 3-dimensional (3D), fast spoiled gradient recalled acquisition in steady state (GRASS) method (spine phased-array coil; repetition time, 5.9 ms; echo time, 2.4 ms; flip angle, 25 degrees; number of excitations, 2; matrix size, 256 × 128; slice thickness, 1.6 mm; number of slices, 12; zero-fill interpolation [section ZIP 4, in-plane ZIP 512] providing 48 slices), with no phase wrap, FOV of 24 cm, and oblique-coronal section along the posterior line of the vertebral body. The

MR input/output gain was standardized (mean ± standard deviations, 155.0 ± 7.3/13.0 ± 0.0, respectively).

The contrast agent, gadopentetate dimeglumine (Omniscan; Daiichi-Sankyo, Tokyo, Japan), was injected into the median cubital vein (0.2 mmol/kg, 4 mL/s) with a saline flush (20 mL). A power injector (SONIC SHOT 50, Nemoto Kyorindo, Tokyo, Japan) was used in all patients. By using first-phase acquisition synchronized to the start of the injection, 5 dynamic scans were obtained (first to fifth consecutive scan phases). Each scan time was 23 to 25 s. After 5 dynamic scans, an additional scan was obtained (sixth phase) with an adjusted FOV to cover the posterior half of the aorta to detect the branching level of the feeding artery. After data acquisition, the images were stored as digital imaging and communications in medicine (DICOM) datasets and displayed on a diagnostic monitor (Flexscan L365; EIZO NANAIO, Ishikawa, Japan) at a 0.4-mm reconstruction pitch.

Image reconstruction

Image reconstruction was the same as previously reported.⁷ The acquired datasets were transmitted to a workstation (Advantage Windows, GE Medical Systems). A 3D maximum intensity projection (MIP) image⁸ in the anteroposterior direction was reconstructed for each of the 5 phases. The resulting five 3D-MIP source images were used for subtraction. The 3D-MIP phase-2 to -5 source images were subtracted from the phase-1 image for noise reduction. A partial MIP image was also used for subtraction. The resulting five 3D-MIP source images were used for double-subtraction (i.e., subtraction of the venous-phase 3D-MIP image from the arterial-phase 3D-MIP image yielded a double-subtracted arterial 3D-MIP image).^{7,9} The curved multi-planar reconstruction (MPR) image was reconstructed and combined with the arterial-phase image and phase-6 image to evaluate the arterial continuity from the aorta to the anterior spinal artery via the artery of Adamkiewicz (Fig. 1).

Detection criteria

The criteria for detection of the artery of Adamkiewicz in both the original and the 3D-MIP images were as previously reported:^{5,7} 1) depiction of a clearly defined blood vessel connected to the radiculomedullary or lumbar artery in the early phase, 2) depiction of a blood vessel running toward the anterior spinal cord with a hairpin-turn connection in the early phase, and 3) diminished signal intensity of this vessel in the late phase. Using curved MPR images, the vertebral level of ar-

Fig. 1. Magnetic resonance angiography (MRA) images of a 78-year-old man with a Crawford I aneurysm: **(a)** arterial phase, **(b)** venous phase, and **(c)** curved multi-planar reconstruction (MPR). MRA demonstrated the artery of Adamkiewicz in the arterial phase **(a)**. The artery's signal intensity diminished in the venous phase **(b)**. The artery of Adamkiewicz branched from the right side at the intervertebral foramen T9, and its feeding artery branched at the same level from the aorta **(c)**.

terial branching from the aorta and the level at the intervertebral foramen were also evaluated.

Two MRA readers independently judged all images according to these criteria to detect the artery of Adamkiewicz and determine the branching levels; disagreements about any aspect, i.e., branching level, side of origin [laterality], or number of vessels, were settled by consensus.

Statistical analysis

Detectability of the artery of Adamkiewicz was compared between the patients with aneurysm versus those with dissection by Mann-Whitney U test. $P < 0.05$ was considered significant (StatView ver 4.58; Abacus Concepts Inc., Berkeley, CA, USA).

Results

The artery of Adamkiewicz was detected in 67 (81.7%) of the 82 patients. All of those 67 had vessels that coursed toward the anterior spinal cord

and were supplied by the intercostal artery (Fig. 1). Branching of the artery of Adamkiewicz occurred either on the left side of the body ($n = 52$; 77.6%) at T7 ($n = 6$), T8 ($n = 5$), T9 ($n = 13$), T10 ($n = 19$), T11 ($n = 7$), or T12 ($n = 2$) or on the right side ($n = 15$; 22.4%) at T7 ($n = 1$), T8 ($n = 2$), T9 ($n = 7$), T10 ($n = 1$), T11 ($n = 3$), or T12 ($n = 1$) (Fig. 2).

The artery of Adamkiewicz was detected clearly along its entire course (starting with feeding arteries branching from the aorta and ultimately feeding into the anterior spinal artery) in 55 (67.1%) of the 82 patients, with aneurysm diagnosed in 44/55 patients (80.0%) and dissection in 21/25 (84.0%). Branching of the intercostal artery from the aorta occurred on the left side of the body at T7 ($n = 3$), T8 ($n = 4$), T9 ($n = 10$), T10 ($n = 17$), or T11 ($n = 7$), on the right side at T8 ($n = 1$), T9 ($n = 5$), T10 ($n = 2$), T11 ($n = 3$), or T12 ($n = 1$), or as an anastomosis at T10–11 ($n = 2$). There was no statistical difference in the rate of detecting the artery of Adamkiewicz between the patients with aneurysm and with

Fig. 2. Frequencies of the vertebral level of arterial branching and of the laterality of the artery of Adamkiewicz in 67 patients.

dissection ($P=0.673$). No cases of collateral blood supply to the artery of Adamkiewicz were found in this study.

When comparing the branching level of the artery of Adamkiewicz at the intervertebral foramen with that of its feeding artery from the aortic wall, the same vertebral level of branching was found in 44 of the 55 patients (80.0%; mean age $\pm$ standard deviation, 67.8 ± 11.4 years), and a difference of one level (above or below the other vertebral level) was detected in 10 of 55 patients (18.2%; mean age 70.5 ± 8.6 years). Only one patient (1.8%) had a difference of 2 vertebral levels between the level at the intervertebral foramen versus the level at the aortic wall (Fig. 3). No patient had compression fracture or vascular anomalies.

Discussion

The artery of Adamkiewicz can now be detected noninvasively with MR angiography.^{4,5,10-13} The use of these imaging techniques for preoperative analysis and surgical planning enables selective reconstruction of the feeding radiculomedullary artery.^{4,5,14} However, it is difficult to reconstruct the artery of Adamkiewicz itself because of its small size (about 0.5 mm in diameter) and its branching from the intercostal/lumbar artery at the intervertebral foramen. Therefore, in the surgical approach, 2 methods are used to maintain the blood flow to the artery of Adamkiewicz. First is to reconstruct the intercostal/lumbar artery feeding the blood flow to the artery of Adamkiewicz, which is the method used when its branching origin is within the vertebral level of the aortic graft replacement. The other method is to adjust the cross-clamping level according to the vertebral level to maintain the

Fig. 3. Comparison of the vertebral level of arterial branching: artery of Adamkiewicz at the intervertebral foramen versus intercostal/lumbar feeding artery branching from the aorta.

flow to the artery of Adamkiewicz, which is used when its branching level is above/below the aortic graft replacement level.

In our review of the literature, we found no report discussing the difference in branching level between the artery of Adamkiewicz at the intervertebral foramen and the feeding artery originating from the aortic wall. In this study, we detected the same vertebral level of branching in 80.0% and a difference of only one vertebral level in 18.2%.

In patients in whom MRA could detect the entire trajectory of the artery of Adamkiewicz and its feeding arteries from the aorta, the critical intercostal/lumbar arterial reconstruction proved adequate to maintain the blood flow to the spinal cord. However, the overall rate of detection of the artery of Adamkiewicz was limited to 81.7% of patients, and we were able to evaluate the entire continuity of the vasculature from the aorta to the anterior spinal artery in only 67.1%. We considered 4 fac-

tors that might affect the branching level difference: aortic elongation, decreasing vertebral height, vascular formative anomalies, and collateral supply. In our case series, there was no evidence of vertebral compression nor vascular formative anomalies. The group of patients with a different vertebral level of branching had a slightly higher mean age than those with the same branching level, but this difference was not statistically significant. We hypothesized that aortic elongation is the factor most likely to affect the branching level and thus contribute to a difference in the branching level in individual patients.

Our study limitations included difficulties in detecting all collateral arteries feeding into the artery of Adamkiewicz because of the limited FOV and difficulties in differentiating this artery from veins. Collateral arteries feeding into the artery of Adamkiewicz may enhance the detection of the arterial vasculature branching from the aorta. It is still controversial that the collateral vessels can feed blood into the spinal cord,^{13,15} and occlusion of the artery of Adamkiewicz may not be the only causative factor affecting spinal ischemia.¹⁶ However, actual cases of spinal cord ischemia after endovascular repair of the aorta continue to be reported,¹⁷ and increase in biochemical markers of ischemic spinal cord injury was documented in an experimental canine study of stent-graft implantation at a critical aortic segment.¹⁸ Our study demonstrated that the artery of Adamkiewicz can be detected at a high rate preoperatively, allowing evaluation of the risk of occlusion of this artery, which could affect the likelihood of spinal complications.

We used a double dose of contrast to visualize the artery of Adamkiewicz. According to recent reports, nephrogenic systemic fibrosis can develop and cause severe damage in patients with renal insufficiency who undergo contrast-enhanced MR imaging,^{19,20} so use of a high dose of contrast has a disadvantage in terms of patient safety. However, in our study population, no patient had renal insufficiency and no case of nephrogenic systemic fibrosis was reported in the follow-up period. It has been shown that the renal artery can still be detected without contrast enhancement.²¹ Using this MRA technique with high spatial resolution, the artery of Adamkiewicz could potentially be detected without contrast enhancement. Further evaluation will be needed to demonstrate useful noncontrast MRA in patient with severe renal damage.

Conclusions

Double-subtraction MRA is a useful noninvasive

technique for detecting the artery of Adamkiewicz and the vertebral level of its feeding arteries branching from the aorta. Using this information to plan surgical strategy, it is possible to reconstruct the artery of Adamkiewicz to reduce the risk of spinal complications. In particular, for clinical use in patients with thoracoabdominal aortic lesions, MRA can be included in the preoperative work-up to localize the segmental trajectories of vessels supplying blood to the artery of Adamkiewicz.

Acknowledgments

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