Clinical Utility of Turbo Contrast-Enhanced MR Angiography for the Major Branches of the Aortic Arch *

Su Ok Seong, Kee-Hyun Chang, Moon Hee Han, Hong Dae Kim, In Chan Song, Kyung Mo Yeon, Man Chung Han.

Purpose : To assess the clinical utility of turbo contrast-enhanced magnetic resonance angiography (CE MRA) in the evaluation of the aortic arch and its major branches and to compare the image quality of CE MRA among different coils used.

Materials and Methods : Turbo three-phase dynamic CE MRA encompassing aortic arch and its major branches was prospectively performed after manual bolus IV injection of contrast material in 29 patients with suspected cerebrovascular diseases at 1.0 T MR unit. The raw data were obtained with 3-D FISP sequence (TR 5.4 ms, TE 2.3 ms, flip angle 30, slab thickness 80 mm, effective slice thickness 4.0 mm, matrix size 100×256, FOV 280 mm). Total data acquisition time was 40 to 60 seconds. We subjectively evaluated the image quality with three-rating scheme : "good" for unequivocal normal finding, "fair" for relatively satisfactory quality to diagnose 'normal' despite intravascular low signal, and "poor" for equivocal diagnosis or non-visualization of the origin or segment of the vessels due to low signal or artifacts which needs catheter angiography. At the level of the carotid bifurcation, it was compared with conventional 2D-TOF MRA image. Overall image quality was also compared visually and quantitatively by measuring signal-to-noise ratios (SNRs) of the ascending aorta, the innominate artery and both common carotid arteries among the three different coils used (CP body array(n=12), CP neck array(n=9), and head-and-neck(n=8).

Results : Demonstration of the aortic arch and its major branches was rated as "good" in 55% (16/29) and "fair" in 34% (10/29). At the level of the carotid bifurcation, image quality of turbo CE MRA was same as or better than conventional 2D-TOF MRA in 65% (17/26). Overall image quality and SNR were significantly greater with CP body array coil than with CP neck array or head-and-neck coil.

Conclusions : Turbo CE MRA can be used as a screening exam in the evaluation of the major branches of the aortic arch from their origin to the skull base. Overall image quality appears to be better with CP body array coil than with CP neck array coil or head-and-neck coil.

Index words : Blood vessels, MR ;
Magnetic resonance(MR), contrast enhancement ;
Magnetic resonance(MR), vascular studies, angiography

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Introduction

Magnetic resonance angiography (MRA) has been widely used in the evaluation of cervical and intracranial vascular diseases. Principal MR angiographic techniques include two-dimensional (2D) and three-dimensional (3D) time-of-flight (TOF) and phase-contrast techniques. In 2D and 3D-TOF imaging, inflow of unsaturated blood generates intravascular signal, whereas in phase-contrast imaging, net accumulated phase shift from flowing blood produces the signals. Because the image quality obtained with these techniques depends on blood flow pattern for vascular contrast, it may be degraded in patients with intravascular slow or turbulent flow, and vascular abnormalities that disturb the normal blood flow pattern. In addition, the proximal portions of the major branches of the aortic arch including vertebral arteries are not satisfactorily imaged with current non-enhanced MRA using either 2D- or 3D-TOF or phase-contrast technique.

Contrast-enhanced MRA (CE MRA) has been proposed as a way of reducing the dependence on blood flow for vascular contrast (1 — 4). If contrast material is injected, the blood T1 can be reduced sufficiently to allow imaging based on T1 contrast with less dependence on inflow effects. Additionally, the positioning of the image volume is less critical in CE MRA. Therefore, CE MRA can image a long length of artery in contrast to conventional TOF or phase-contrast technique.

The purpose of this study is to evaluate the clinical utility of turbo CE MRA in the evaluation of the major branches of the aortic arch, and to compare the image quality of CE MRA among the different coils used.

Materials and Methods

In 29 patients with suspected cerebrovascular diseases, 20 men and 9 women ranging in age from 32 to 78 years old (mean 57.2 years), turbo CE MRA of the neck vessels encompassing from the aortic arch up to the distal cervical portion of the internal carotid artery were prospectively performed. Conventional non-enhanced 2D-TOF MRA was also obtained for the intracranial proximal vessels in all patients and for the common carotid bifurcation in 26 patients. In only four of these patients, digital subtraction angiography was done.

After precontrast MRA was performed, serial three-phase dynamic CE MRA images were obtained approximately 10, 20 and 30 seconds after beginning of intravenous injection of a single-dose bolus (0.1 mmol/kg, 15 — 20 ml) of gadopentetate dimeglumine (Magnevist® Berlex Laboratories, Wayne, NJ) (Fig. 1). The contrast material was injected manually into the antecubital vein through 18 gauge needle, and each bolus was followed immediately by a 15ml saline flush. The MR scan was initiated approximately 7 — 10 seconds after beginning of contrast material injection. The raw data was obtained in coronal plane before and after contrast material injection using the same 3D FISP MRA sequence (TR 5.4 msec, TE 2.3 msec, flip angle 30°, slab thickness 80 mm, effective slice thickness 4 mm, matrix size 100 × 256, field of view(FOV) 280 mm, total data acquisition time 40 — 60 sec) at 1.0 T superconductive magnet (Magnetom Expert, Siemens, Erlangen, Germany). The data were reconstructed with maximum intensity projection (MIP) in the standard way. Subtraction of the precontrast data from the postcontrast data was performed to create an image which mostly contains information from vascular flow. Three different types of commercial coils covering the entire neck were used in CE MRA in order to

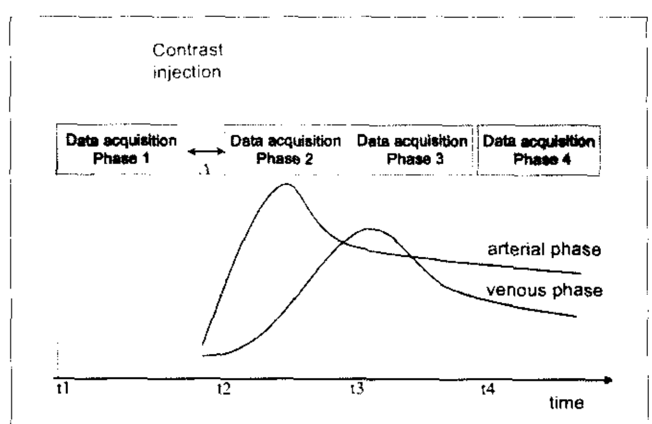


Fig. 1. Injection and scan protocol scheme for turbo dynamic contrast-enhanced MRA After the end of the first scout imaging without injection of the contrast material, the bolus injection is started. After a wait period Δ of 7 to 10 seconds (depending on patient's cardiac output), three more imagings are performed without any pause in between. After completion of the reconstruction, the final MRA images are obtained by subtracting the precontrst scout imaging from the contrast-enhanced immaging.

compare the overall image quality among the different surface coils used ; circularly polarized (CP) body array coil (n=12), CP neck array coil (n=9), and head-and-neck coil (n=8).

Two radiologists subjectively evaluated the image quality of the CE MRAs. First, each great vessel in a given patient was graded as follows : "good" for unequivocal normal finding, "fair" for relatively satisfactory to diagnose 'normal' despite intravascular less signal, and "poor" for equivocal diagnosis or non-visualization of the origin or other segment of the vessels due to low signal or artifacts which needs catheter angiography (Fig. 2a—d). Each vessel was rated at both the origin site and the remaining segment other than the origin with the best arterial phase image selected from CE MRA images of three-phases. The vessels evaluated included the innominate, both the common carotid, both the subclavian, and both the vertebral arteries. Second, after three grades were scored ("good" = 3, "fair" = 2, and "poor" = 1) the overall image quality of CE MRA in each patient was arbitrarily rated as one of three-rating scheme ; "good" for average score of 2.5 or more in a given patient, "fair" for average score of 1.8—2.4, and "poor" for average score of 1.7 or less. Third, at the carotid bifurcation level the overall im-

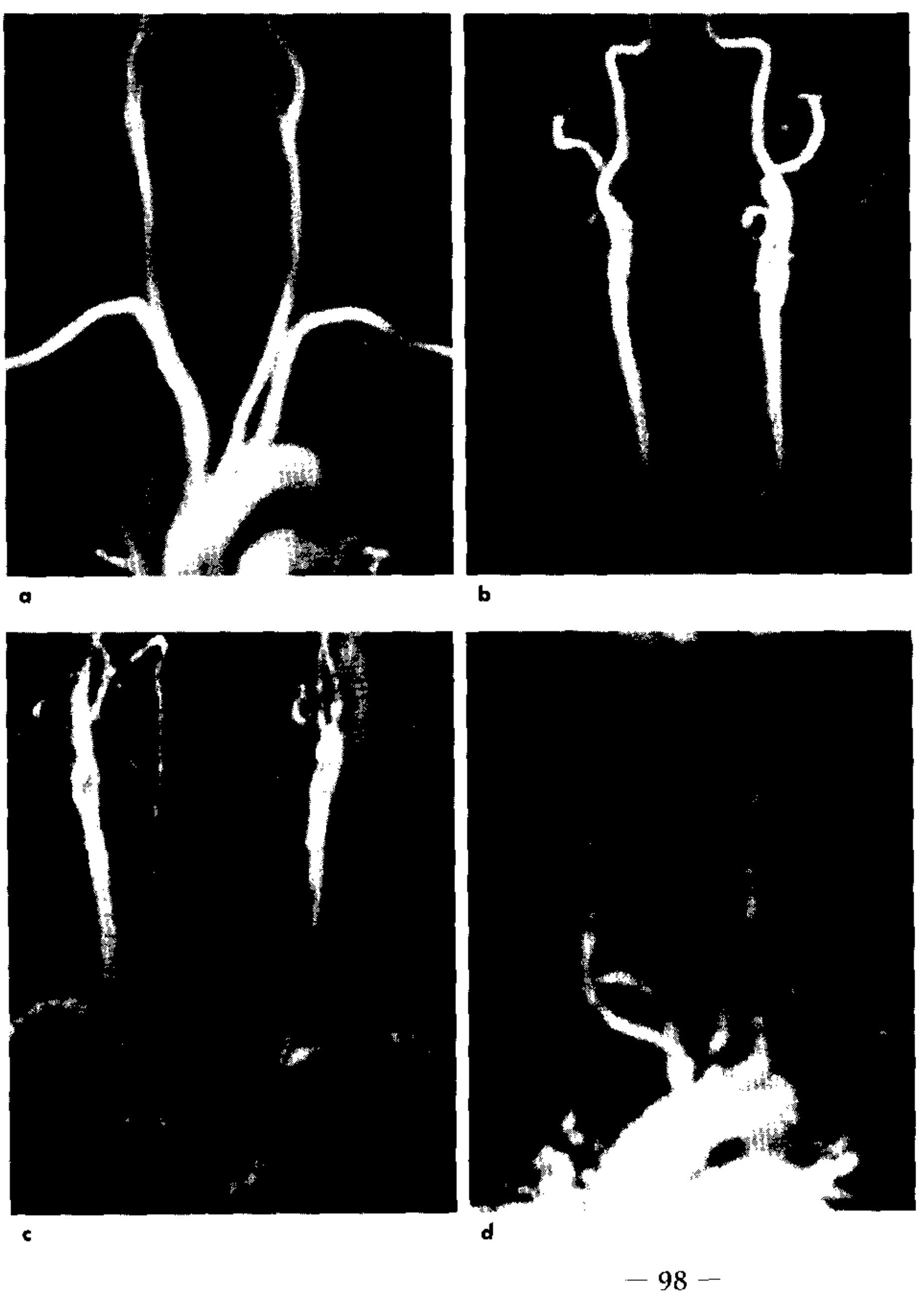


Fig. 2. Examples of subjective rating of image quality (**a**) "good" ; The entire course including origins of the major branches of the aortic arch is clearly delineated for unequivocal normal finding.
(**b**) "fair" ; The innominate, left common carotid, and left subclavian arteries are well visualized through entire course from the origin, although aortic arch shows relatively low signal intensity resulting from peripheral positioning of FOV.
(**c**) "poor" ; The proximal portions of the major branches of the aortic arch including both vertebral arteries appear to be stenotic, which needs catheter angiography.
(**d**) "poor" ; The arteries distal to the carotid bifurcation are poorly visualized mainly due to aliasing artifact.

age quality of CE MRA was compared visually with that of the conventional 2D-TOF MRA images obtained in 26 patients. Lastly, overall image quality of CE MRA was compared among the images obtained using three different coils visually and by measuring the signal-to-noise ratios (SNRs) at the ascending aorta just proximal to the innominate artery, the innominate artery, and both the common carotid arteries just proximal to the bifurcation. Student unpaired t-test (SPSS/PC+ver 4.01) was used for statistical analyses.

Results

Among the three phases of dynamic CE MRA, the first phase (arterial phase) images best demonstrated the entire course of the major branches of the aortic arch including their origins in most cases. In the second- and third-phase images, the arteries and the veins in the neck were variably superimposed, making the arterial evaluation difficult.

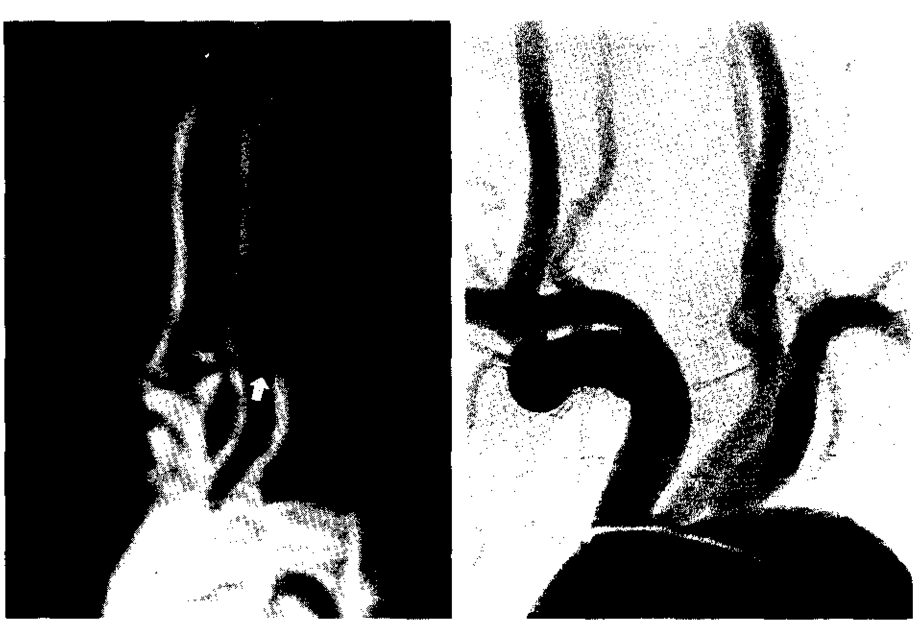
The origin of the each vessel was rated as either "good" or "fair" in 100% (29/29) for the innominate artery, 93% (27/29) for the right common carotid artery, 83% (24/29) for the left common carotid artery, 100% (29/29) for the right subclavian artery and 93% (27/29) in the left subclavian artery. The origins of the vertebral arteries were rated as either "good" or "fair" in 59% (17/29) in the right and in 72 % (21/29) in the left side (Fig. 3a and b). The remaining segment of the vessel other than the origin site was rated as either "good" or "fair" in 97% (28/29) for the innominate artery, 100% (29/29) for the right subclavian artery, 93% (27/29) for the left subclavian artery and both common carotid arteries, and 83% (24/29) for the both vertebral arteries (Table 1). The overall image quality was rated as "good" in 55 % (16/29) and "fair" in 34% (10/29).

At the levels of the carotid bifurcation, overall im-

Table 1. Subjective Rating of the Major Branches of the Aortic Arch in Turbo Contrast-Enhanced MR Angiography (n=29)

		Good	Fair	Poor
IA	Origin site	14	15	0
	Remainder	19	9	1
R-SA	Origin site	22	7	0
	Remainder	21	8	0
L-SA	Origin site	21	6	2
	Remainder	18	10	1
R-CCA	Origin site	19	8	2
	Remainder	25	2	2
L-CCA	Origin site	16	8	5
	Remainder	22	4	3
R-VA	Origin site	12	5	12
	Remainder	16	9	4
L-VA	Origin site	11	10	8
	Remainder	13	10	6

IA ; Innominate artery, CCA ; Common carotid artery
SA ; Subclavian artery, VA ; Vertebral artery
R ; Right, L ; Left



a b

Fig. 3. Comparison of CE MRA with catheter angiogram. The origin site of the left vertebral artery seems to be stenotic (white arrow) on the rotational oblique view of CE MRA (**a**), which is confirmed on catheter arch aortogram (black arrow) (**b**).

age quality of the CE MRA images were slightly superior in 27% (7/26), similar in 38% (10/26) and inferior in 35% (9/26) to that of the conventional 2D-TOF MRA images(Fig. 4 a and b).

Overall image quality of CE MRA studied with CP body array coil appeared to be slightly superior or similar to those with either CP neck array coil or head-and-neck coil. SNRs of the ascending aorta and the innominate artery were significantly greater with CP body array coil than with either CP neck array or head-and-neck coil ($p < 0.05$). However, SNRs of both the common carotid arteries were not significantly different among the different coils used (Table 2) (Fig. 5a—c).

Discussion

In the most commonly used inflow technique (2D- and 3D-TOF), the vascular contrast is generated by the difference in saturation between the inflowing spins of the blood and the stationary spins of the tissues in the acquisition volume. In phase-contrast technique, dedicated gradients are used to encode the flowing spins of the blood with an additional phase shift. Unfortunately, none of the available MRA methods can successfully copy with the full range of velocities encountered in the different types of flow. For each individual flow condition, the best suited sequence has to be chosen and its parameters optimized. This specific difficulty represents one of the factors preventing wide application of MRA to the lower neck, body and extremities.

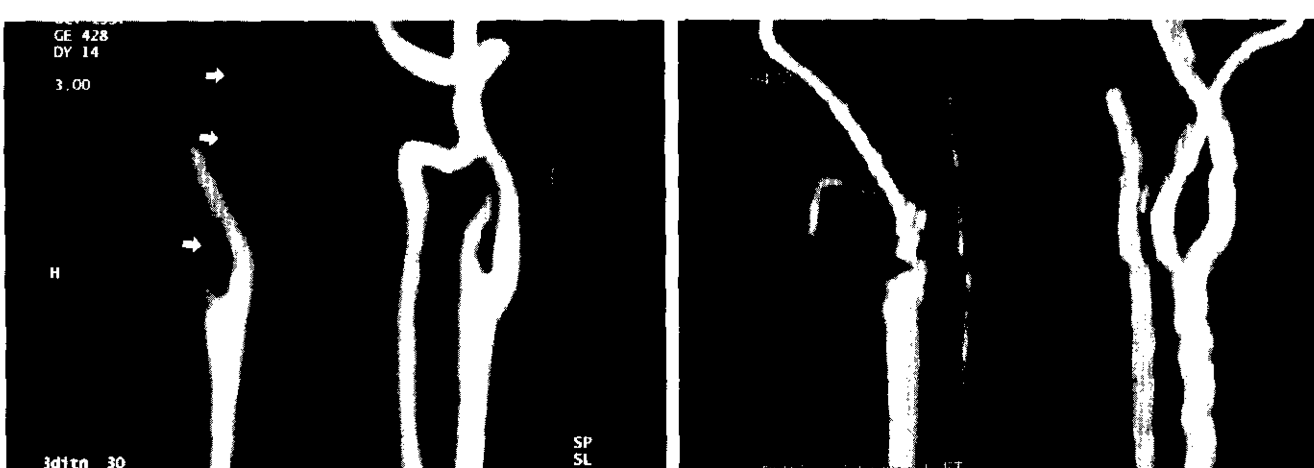
An alternative approach to flow-based MRA is CE MRA, in which use of contrast agents (such as gadolinium compounds) increases the flow signal intensity resulting from the selective shortening of the T1 relaxation time of the blood. Depending on the actual concentration of the contrast material, the arterial blood T1 can be as short as 50—100 msec, substantially shorter than T1 of the fat. Therefore, blood produces the largest signal and will be picked up with the maximum intensity projection (MIP) to create a MR angiogram. Because intravascular signal is primarily related to contrast-enhanced T1 shortening, spin saturation artifacts from slow flow or in-plane flow can be eliminated. The short echo times for the arterial phase CE MRA help to minimize

Table 2. Signal-to-Noise Ratios of the Arteries with Different Coils Used (mean ± SD)

Coil (n)	AA	IA	CCA
CP body array (12)	10.79±3.05*	10.95±3.26*	9.25±1.97
CP neck array (9)	3.94±0.57	5.01±0.52	7.96±2.15
Head-and-Neck (8)	3.01±1.02	4.65±1.25	8.67±2.63

AA ; Ascending aorta IA ; Innominate artery
CCA ; Common carotid arteries
*P<0.05 between CP body array and CP neck array and/or Head-and-Neck

$$^{*}\text{Signal to Noise Ratio (SNR)} = \frac{\text{Signal intensity of artery}}{\text{Signal intensity of background}}$$



a b

Fig. 4. Comparison of CE MRA with 2D-TOF MRA. CE MRA (**a**) shows diffuse small caliber of the right internal carotid artery with low signal intensity suggesting severe stenosis of the proximal internal carotid artery (arrows), which is more clearly delineated than conventional 2D-TOF MRA (**b**) showing motion artifact with venetian blind appearance.

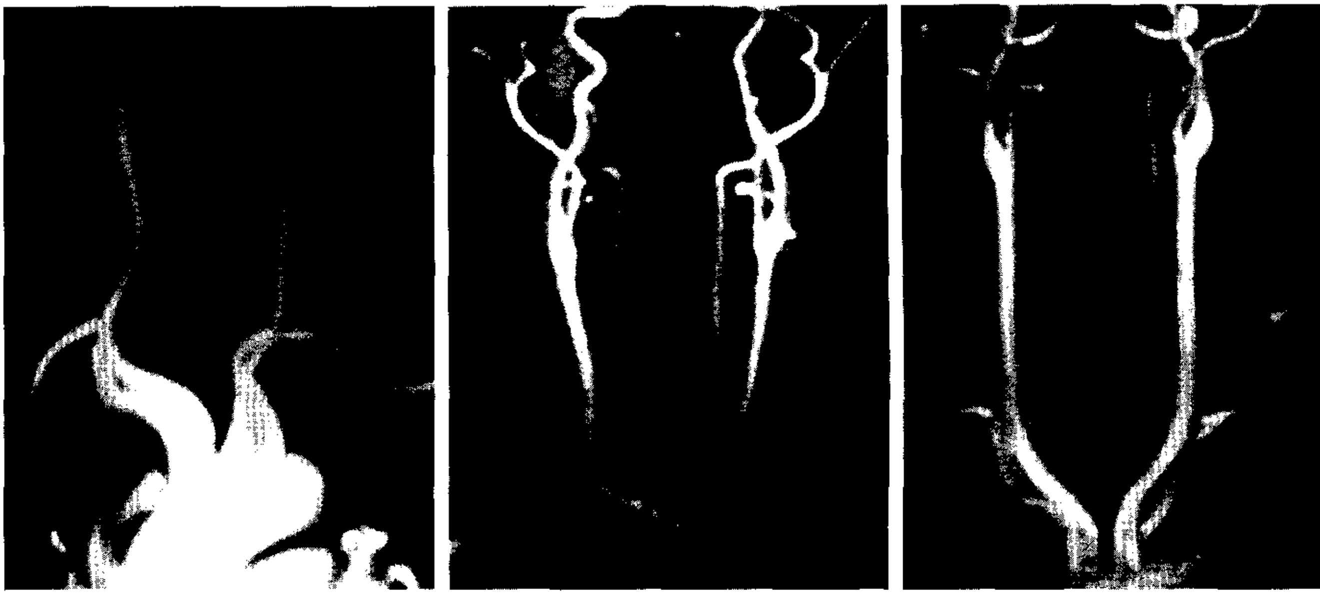


Fig. 5. Comparison of CE MRAs obtained using three different coils. Overall image quality of CE MRA with CP body array coil (**a**) appears to be better than that with CP neck array coil (**b**) or head-and-neck coil (**c**).

intravoxel spin dephasing in stenotic regions that have fast or turbulent flow.

A new technique was proposed to keep the voxel size small while measuring fewer data in k-space and thus reducing the scan time. The technique can also be used to create thinner partitions in the 3D data set to improve the quality of the MR angiograms without a scan time penalty. This option is particularly useful in combination with CE MRA sequences.

Unlike the conventional TOF MRA, a specific orientation of the imaging volume with respect to the major flow direction is less critical in CE MRA. Therefore, the imaging volume can be positioned in a way to get the maximum vessel coverage in a minimum scan time. The direction of the read gradient is chosen to be along the longest dimension of the vasculature with a FOV to get sufficient coverage, but still providing an adequate SNR. This permits imaging in the plane of the arteries so that a small number of slices can image a long length of artery for a net reduction in total scan time.

It is ideal for the data acquisition (in particular the center of k-space) to occur when the contrast agent maximally arrives at the vessels being imaged. Therefore, precise timing of signal acquisition is essential in CE MRA (Fig. 1). The acquisition window of the scan must be set to get the peak of the arterial phase. Boos et al (presented at the International Society for Magnetic Resonance in Medicine, Canada, 1997) performed CE MRA of the carotid arteries in an extremely narrow time interval of 8 to 9 sec or 15 to 20 sec using half-Fourier acquisition. Levy et al (6) reported that the maximum arteriovenous signal intensity difference (from 40 to 60 intensity units) in the carotid artery began approximately 20 sec after the start of the intravenous infusion of a bolus of contrast material and lasted approximately 10 sec. A point approximately 25 sec after initiation of the bolus of contrast agent corresponded to the center of the period of maximum arteriovenous signal intensity difference in the carotid arteries. Therefore, they initiated scanning 11 sec after starting to infuse the bolus of contrast agent using single-phase 29 sec data acquisition time. In our study, following the MR scan started 7—10 sec after the start of infusion of contrast agent, three-phase dynamic CE MRA at 10 sec, 20sec, and 30 sec. was performed because of individual variability in times on maximum arteriovenous signal intensity difference.

CE MRA accurately demonstrated the great vessel and the vertebral artery origins in 19 of 20 patients in a study (Murphy et al., presented at the Radiological Society of North America, USA, 1997). In our study, CE-MRA satisfactorily demonstrated the major branches of the aortic arch from their origin site to the skull base in most cases, although the origins of the vertebral arteries were well delineated in less than 80 % of the patients.

Disadvantages of CE MRA are its nonselective character and coincidental venous enhancement, particularly of vertebral veins. To avoid superposition of enhancing soft tissues and vessels and to facilitate the interpretation of these complex nonselective angiograms, we used the targeted subtraction MIP software, which allow us to extract and project portions of the acquired original 3D volume. Stereoscopic viewing of a set of images calculated with an angle difference of 6° also facilitates the differentiation of arteries and veins. Although CE MRA relies on the shortening of the T1 of the blood for its vascular signal, it remains sensitive to the destructive phase dispersion caused by turbulence, and gradient echo sequences with flow refocused gradients are still needed.

In our study, only four among 29 patients underwent catheter angiography. Lack of the gold standard image of catheter angiography limited our results. Further studies may be needed to evaluate clinical utility of CE MRA in more detail for the aortic arch and its branches.

SNR of both the common carotid arteries just proximal to the bifurcation was similar among the CE MRA images obtained by using three different coils. It seems to be good enough to use CP neck array coil or head-and-neck coil in imaging of the carotid bifurcation. However, CE MRA of the aortic arch using CP body array coil showed significantly higher SNR on the ascending aorta and the innominate artery than using CP neck array coil or head-and-neck coil. Our results suggest that CP body array coil may well be used for the better quality of CE MRA, particularly for assessing the proximal port-ions of the major branches of the aortic arch.

In conclusion, turbo CE MRA well delineated the great vessels of the aortic arch including the vertebral arteries from their origin to the skull base. It can be used as a screening exam in the evaluation of the aortic arch and its major branches. Overall image quality of CE MRA encompassing aortic arch and its major branches appeared to be better with CP body array coil than with CP neck array coil or head-and-neck coil.

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대동맥궁 주요 분지들의 고속 조영증강 자기공명혈관조영술의 임상적 유용성

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목 적: 고식적인 자기공명혈관조영술 (MR Angiography, MRA)기법으로는 영상화가 어려웠던 대동맥궁의 주요 분지들의 평가에 있어서 새로운 MR기법인 조영증강 MRA의 임상적 유용성을 알아보고, 그 화질을 사용한 코일의 종류에 따라 비교해 보고자 한다.

대상 및 방법: 뇌혈관 질환을 의심하여 고식적인 기법으로 뇌 및 경동맥 MRA를 시행한 29명에서 전향적으로 Gd-DTPA 15-20ml를 일시에 손으로 주입한 후 대동맥궁과 그의 주요 분지들에 대해 3시기의 고속 MRA를 시행하여 그 화질을 분석하였다. MRA는 1.0 T MR기종에서 3D-FISP기법으로 얻었으며 총 영상 획득 시간은 40-60초였다. 영상 분석은 무명동맥, 양측 총경동맥, 양측 쇄골하동맥과 양측 척추 동맥들의 기시부로부터 전장에 걸쳐 화질을 주관적으로 3등급(good ; 명백히 정상 소견을 보이는 경우, fair ; 약간 낮은 신호를 보이나 정상으로 진단하기에 비교적 만족할 만한 경우, poor ; 협착이 모호하거나, 인공물이나 너무 낮은 신호로 혈관을 볼 수 없어 카테터 혈관조영술을 요하는 경우)으로 나누어 평가하였으며, 양측 총경동맥의 분기(bifurcation)부위에서는 고식적인 기법의 영상과 그 화질을 비교평가하였다. 또한 세가지 사용한 코일의 종류(CP body array 12예, CP neck array 9예, head-and-neck 8예)에 따른 화질 차이를 정성적 및 정량적(신호대 잡음비)으로 분석하였다.

결 과: 대동맥궁 주요 분지들의 전반적인 화질은 55% (16/29)에서 'good', 34% (10/29)에서 'fair'로 평가되어 대부분 고식적인 카테터 혈관조영술이 필요치 않을 정도로 만족할 만한 화질을 보였다. 양측 총경 동맥 분지 부위에서는 65% (17/26)에서 고식적인 3D-TOF기법과 같거나 나은 영상을 보였다. CP body array 코일을 사용한 경우가 CP neck array 코일이나 head-and-neck 코일을 사용한 경우보다 정성적 및 정량적으로 유의하게 나은 영상을 보였다($p<0.05$).

결 론: 고속 조영증강 MRA기법은 단시간내 (40-60초)에 대동맥궁의 주요 분지들을 그 기시부위부터 두개골 저부에 이르기까지 대부분에서 잘 나타내주므로 선별검사로서 임상적으로 유용하리라 생각되며 CP body array코일을 사용하였을 경우에 CP neck array코일이나 head-and-neck코일을 사용한 경우보다 좀더 나은 화질을 얻을 수 있으리라 생각된다.

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