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Optimal Region of Interest Location of Test Bolus Technique in Extra Cranial Carotid Contrast Enhanced Magnetic Resonance Angiography

Kwan-Woo Choi[1], Sa-Ra Na[1], Soon-Yong Son[2], and Mi-Ae Jeong[3]*

[1]*Asan Medical Center, 88, Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea*
[2]*Wonkwang Health Science University, 514, Iksan-daero, Iksan-si, Jeollabuk-do 54538, Republic of Korea*
[3]*Department of Dental Hygiene, Kangwon National University, Samcheok 25913, South Korea*

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This study is aimed to optimize a location of region of interest (ROI) in test bolus carotid contrast enhanced magnetic resonance angiography (CE-MRA) at 3.0T. A total of consecutive 270 patients with no cardiovascular and vessel diseases were selected. Patients underwent elliptical centric 3D CE-MRA with the test bolus technique to identify the individual arterial arrival time. Quantitative measurements were performed by drawing ROIs of 25 mm^2 and signal intensities (SI) were measured in the center of common carotid artery (CCA), internal carotid artery (ICA) and aortic arch (AA). As a result, ROIs located within AA showed a significantly clarified arterial peak and over three times increased SI, while no significant arterial peak time differences were observed compared to ROIs located within CCA. In conclusion, it was demonstrated that the aortic arch is the optimal position to locate ROI in test bolus images of the carotid CE-MRA.

Keywords : carotid imaging, MR Angiography (MRA), test bolus

1. Introduction

Contrast enhanced magnetic resonance angiography (CE-MRA) of the extra cranial carotid arteries has a high sensitivity of 94 % and a specificity of 92 % for the diagnosis of severe carotid artery stenosis in a relatively quick scan time covering extensive length of vessels at high spatial resolution [1, 2]. It was enabled with the use of the elliptical-centric phase reordering technique to sample the k-space data in combination with a bolus arrival scan or fluoroscopic triggering to identify the individual arterial arrival time. Although the fluoroscopic triggering has an advantage of simplicity, test bolus technique is usually preferred in clinic circumstances as the shape and exact timing of the main bolus can be accurately predicted. The test bolus technique can be performed prior to acquisition of CE-MRA dataset using a small gadolinium contrast dose of 1mL. The arterial peak enhancement time is then determined using an ROI analysis [3-6].

However in clinical circumstances, the ROI have commonly been drawn in common carotid artery (CCA) because it is on the center of images and several problems have arose especially when the diameter of common carotid artery is too small or the peak of the time intensity curve is vague. Occasionally it is difficult to accurately visualize the GBCA arrival in the carotid arteries, especially in patients with poor cardiac output. The faulty timing have led to an insufficient arterial (ringing artifact) or venous overlap (venous contamination) of important arterial structures [7, 8]. To optimize an image quality of the CE-MRA, the contrast must be timed to ensure maximal enhancement of the arterial system without venous enhancement.

Thus, in this paper we aim to compare among ROIs in common carotid artery (CCA), internal carotid artery (ICA) and aortic arch (AA) which are drawn in the test bolus images.

2. Materials and Methods

2.1. Patient population and the Image acquisition

Form January and March in 2016, a total of consecutive 270 patients with no cardiovascular and vessel diseases who came for medical check-up were selected. There were 156 men and 114 women with a mean age of 59.90

*Corresponding author: Tel: +82-33-540-3391
Fax: +82-33-540-3399, e-mail: teeth2080@ kangwon.ac.kr

± 9.38.

The patients underwent elliptical centric 3D CE-MRA using a test bolus technique to identify the individual arterial arrival time. As an image acquisition device, we used a 3.0T superconductive magnetic resonance imaging device (Achieva, Philips medical system, Netherlands). The body coil was used as the transmitter, and a dedicated, 16-channel SENSE head and neck coil was used as the receiver. Test bolus images were acquired with auto injector (Spectris Solaris EP, medrad. The test bolus sequence was performed prior to acquisition of CE-MRA using a small Gd contrast dose of 1mL followed by a 20 mL saline flush at the same rate as planned for the actual injection through superficial vein in right hand. Multiple, single-slice, fast gradient echo images in the vascular region of interest are acquired as rapidly as possible (every 1-2 seconds) for approximately 1 min. MRI scanning was performed using the following protocol: coronal FFE (fast field echo) SPIR (spectral pre saturation with inversion recovery) sequence (TR/TE, 17/2.1 msec; flip angle, 30 degress; FOV, 320×320 mm^2; matrix size, 256×256; slice thickness, 80 mm; dynamic scan time, 1 sec; dynamic scans, 150; number of excitation, 1).

2.2. Statistical method and analysis of clinical data

For the quantitative analysis, ROIs with 25 mm^2 area were located in the center of AA, CCA and ICA (Fig. 1). The time-intensity curves were calculated with Image J. The signal intensities were measured in an arbitrary unit which is determined by numerous parameters (e.g. TR, TE, flip angle, etc.). We compared both of the arterial peak times and signal intensities of the three ROIs by using ANOVA and Duncan's post hoc test. All statistical analysis was performed using the SPSS software package (version 18; SPSS Inc., Chicago, IL, USA).

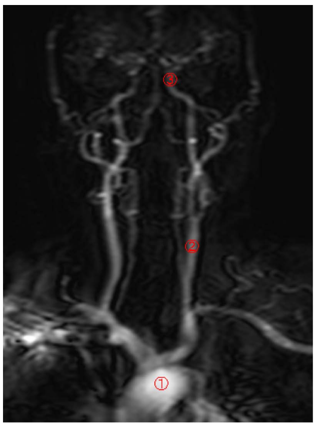


Fig. 1. An image of test bolus sequence after intravenous gadolinium injection of 1mL. There are three ROIs in the middle of the CCA, ICA and aortic arch.

Table 1. Socio-demographical variable of the patients.

Spec.		Frequency	Percent (%)
Gender	Male	156	57.8
	Female	114	42.2
Age	40 under	3	1.1
	40~49	33	12.2
	50~59	96	35.6
	60~69	102	37.8
	70~79	33	12.2
	80 up	3	1.1
Height (cm)	150 under	6	2.2
	150~159	84	31.1
	160~169	90	33.3
	170~179	87	32.2
	180 up	3	1.1
Weight (kg)	50 under	18	6.7
	50~59	75	27.8
	60~69	72	26.7
	70~79	81	30.0
	80 up	24	8.9

3. Results

The arterial peak times of aortic arch and common carotid artery were statistically coincided while internal carotid artery peak was relatively inaccurate and late ($p < 0.05$). The mean arterial peaks of aortic arch, common carotid artery and internal carotid artery were 18.06 ± 3.13, 18.91 ± 3.27 and 20.12 ± 3.27 sec, respectively (Table 2). The results of the statistical analysis conducted with ANOVA analysis and Duncan's post hoc test were summarized in Table 3 and 4.

The maximum signal intensity was the most superior in the aortic arch compared to ROIs of CCA and ICA ($p < 0.001$). The maximum signal intensities test of each ROI

Table 2. Arterial peak time of each ROIs.

Category	Measurement(sec)	
	Avg	SD
Aortic arch	18.06	3.13
Common carotid artery	18.91	3.27
Internal carotid artery	20.12	3.27

Table 3. ANOVA analysis of signal intensity depending on the arterial peak time.

Category	Sum of Squares	Mean Square	F	Sig.
Between Groups	191.43	95.72	9.21	.000
Within Groups	2776.29	10.40		
Total	2967.72			

Table 4. Post hoc test of arterial peak time.

Category	Subset for alpha = 0.05	
	1	2
Aortic arch	18.06	
Common carotid artery	18.91	
Internal carotid artery		20.12
Sig.	.079	1.000

Table 5. The maximum signal intensities of each ROI.

Category	Measurement (SI)	
	Avg	SD
Aortic arch	642.12	336.25
Common carotid artery	209.28	94.32
Internal carotid artery	195.99	93.12

Table 6. ANOVA of maximum signal intensities.

Category	Sum of Squares	Mean Square	F	Sig.
Between Groups	11596653.64	5798326.82	133.16	.000
Within Groups	11626278.04	43544.11		
Total	23222931.68			

was 642.12 ± 336.25 in aortic arch, 209.28 ± 94.32 in CCA and 195.99 ± 93.13 in ICA (Table 5). The maximum signal intensities were analyzed with ANOVA, and the results of the statistical analysis conducted with ANOVA analysis and Duncan's post hoc test were summarized in Table 6.

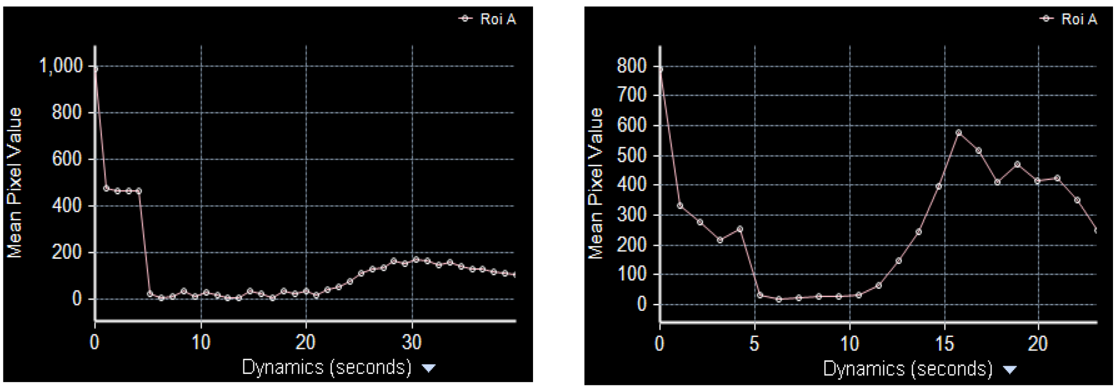
4. Discussion

To accentuate arterial signal in a short scanning time, CE MRA examinations use elliptical-centric ordering technique called CENTRA (Contrast-ENhanced Timing Robust Angiography) to sample the k space. To acquire optimal CE-MRA images, the arterial peak time should be correspond to the center of k-space sampling and also venous signal should be minimized [8, 9]. The lowest spatial frequency points near the center of k-space contribute most to overall image contrast. While the high spatial frequencies of k space are being sampled during the appearance of the venous system as they mostly contribute to the edges and details of the images. Therefore the arterial peak of the test bolus should be precisely measured [10]. Early enhancement causes ringing artifact, while the opposite causes venous appearance on the image [7, 11].

In previous studies, Willinek *et al.*, improved the problems encountered in CE-MRA caused by the matter of unclear arterial peak time using the 4D-TRAK (Time Resolved Angiography with Keyhole) and TRICKS (Time Resolved Imaging of Contrast Kinetics) techniques [12, 13]. Although the two techniques could be performed without considering the delay time of the contrast agent, the spatial resolution is significantly lowered. In clinical circumstances where the CE-MRA is regarded as a gold standard to evaluate the supra aortic to extra or intra-cranial vessel diseases, optimal calculation of the arterial

Table 7. Post hoc test of the maximum signal intensity.

Category	Subset for alpha = 0.05	
	1	2
Common carotid artery	195.99	
Internal carotid artery	209.28	
Aortic arch		642.12
Sig.	.670	1.000



(a) (b)

Fig. 2. (Color online) The graphs show examples of time-intensity curve. (a) The arterial peak time is vague and the signal intensity is low. (b) The arterial peak time can be distinguished clearly with a very high signal intensity.

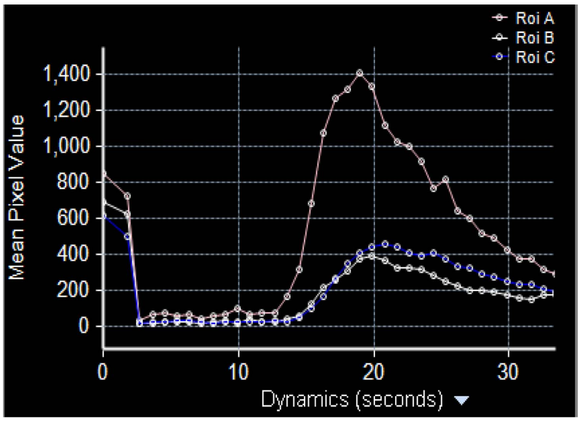


Fig. 3. (Color online) The dedicated ROIs confirm the peak arrival time in each arteries. The quality of the each graph differ in signal intensity, resolution, clarity of the peak depending on the position of the ROIs.

peak time is necessary.

In this paper, we only changed the location of the ROI drawn on the test bolus to optimize the timing of the bolus, maintaining the spatial resolution, scan time and other parameters of the CE-MRA. Our study results suggest that as a reference value of the CCA arterial peak time, ROI drawn on the aortic arch could replace the current CCA ROI method as it has more than three times of signal intensity which means the resolution is three times superior (Fig. 2). Another advantage of setting ROI on the aortic arch, as it has relatively larger are than the any other supra aortic vessel structures, it can prevent a partial volume error occurs when the ROI is larger than the diameter of the artery. Also, the time to low signal intensity plot has improved resolution and smaller FWHM that enables more precise decision of the arterial peak time (Fig. 3). However, this study has a limitation as the subjects only included patients who came for medical check-up.

In spite of this, it is considered meaningful to prove the optimal position of ROI in test bolus images conducted for the CE-MRA by improving the ambiguous arterial peak time arose from the low signal intensity resolution.

5. Conclusion

In the bolus timing approach for more accurate planning and prediction of the shape and exact timing of the main bolus, it was demonstrated that the aortic arch is the optimal position to locate ROI in the carotid CE-MRA.

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