CLINICAL ARTICLE

J Korean Neurosurg Soc 39 : 347-354, 2006

Role of Multislice Computerized Tomographic Angiography in Vasospasm Following Aneurysmal Subarachnoid Hemorrhage

Dong-Mook Park, M.D., Young-Don Kim, M.D., Dae-Young Hong, M.D.,
Gi-Hwan Choi, M.D., Hyung-Tae Yeo, M.D.

Department of Neurosurgery, Daegu Catholic University, School of Medicine, Daegu, Korea

Objective : We evaluate the role of multislice computerized tomographic angiography(MCTA) in the diagnosis of intracranial vasospasm following subarachnoid hemorrhage(SAH) in patients suspected of having vasospasm on clinical ground.

Methods : Between October 2003 and June 2005, patients with ruptured cerebral aneurysms of the anterior circulation clipped within 3 days of the onset were included. We performed follow-up MCTAs in patients who were suspected to have vasospasm on transcranial doppler sonography(TCD) findings and clinical grounds. Based on the clinical presentation of symptomatic vasospasm, we investigated the correlation between clinical, TCD, and MCTA signs of vasospasm and evaluated the role of MCTA in vasospasm.

Results : One hundred one patients met the inclusion criteria and symptomatic vasospasm developed in 25 patients (24.8%). We performed follow-up MCTAs in 28 patients. MCTA revealed spasm in the vessels of 26 patients. The sensitivity of MCTA was 100%. Among the 26 patients with MCTA evidence of vasospasm, 3 patients had TCD signs of vasospasm after symptomatic vasospasm presentation. Another 3 patients with symptomatic vasospasm had no TCD signs of vasospasm in daily serial recordings. Six other patients without symptomatic vasospasm showed MCTA evidence of vasospasm (false positive result) but these patients had also positive TCD signs of vasospasm. Volume rendering(VR) images tended to show significantly more exaggerated vasospasm than maximum intensity projection(MIP) images. The mean cerebral blood flow velocity of both proximal segment of the middle cerebral artery (M1) was significantly correlated with each reduced M1 diameter on MCTA ($P<0.05$).

Conclusion : MCTA could be a useful tool for evaluation and planning management of critically ill patients suspected of having vasospasm; however, more randomized controlled trials are necessary to assess these points definitively.

KEY WORDS : Symptomatic vasospasm · Transcranial Doppler sonography · Multislice computerized tomographic angiography · Maximum intensity projection · Volume rendering.

Introduction

Prompt detection of vasospasm in aneurysmal SAH is important in the prevention of delayed ischemic events. The current standard of reference for detecting vasospasm is digital subtraction angiography(DSA)[29]. However, DSA is an invasive method and has a total complication rate of approximately 5% and a permanent stroke rate of approximately 0.5% to 1%[3,6,10,21]. These complications limit its clinical application. TCD is noninvasive and rapidly performed, but does not provide anatomic information and has operator-dependence and has difficulty in accurately detecting vasospasm at sites other than the proximal middle cerebral artery (MCA). Recently, MCTA has been developed to provide clear vascular images, even in peripheral arteries and it can detect angiographic vasospasm after SAH with accuracy equal to that of DSA[19]. It does not carry the risks of DSA and takes less time than DSA. In this study, follow-up MCTA was performed in patients who were suspected to have vasospasm on TCD findings and clinical grounds. Degree and distribution of vasospasm on VR images and MIP images were acquired and compared with the TCD findings and other various factors.

• Received : August 5, 2005 • Accepted : November 3, 2005
• Address for reprints : Young-Don Kim, M.D., Department of Neurosurgery, Daegu Catholic University, School of Medicine, 3056-6 Daemyeong 4-dong, Nam-gu, Daegu 705-718, Korea Tel : +82-53-650-4257, Fax : +82-53-650-4932, E-mail : shydshyd@cu.ac.kr

Materials and Methods

Between October 2003 and June 2005, 130 patients were admitted to our institution with aneurysmal SAH. Patients with ruptured cerebral aneurysms of anterior circulation clipped within 3 days of the onset were included. The medical records of all patients were reviewed in detail to retrieve information regarding the clinical presentation, location of aneurysm, amount of blood on initial head computed tomography (CT) scan, Fisher grade, modified Fisher grade[8,23], and development of symptomatic vasospasm along with medical and endovascular treatment received. Serial TCD studies of the anterior circulation were performed daily from the day of admission. TCD recordings of mean cerebral blood flow velocity (MCBFV) (cm/sec) were daily recorded through temporal window by using a 2-MHz transducer (MultiDop P; DWL, Überlingen, Germany).

MCTA was performed using Light Speed Plus CT (General Electronic, Milwaukee, WI) with the following parameter : collimation at 1.25-mm and pitch at 0.75. Before scanning was started, 120ml Ultravist (Schering AG, Berlin, Germany) was injected via an antecubital vein at 3ml/s. The scan delay was set by the Smart Prep automatic triggering system (General Electronic). The CT value was measured in the circular regions of interest in the bilateral carotid arteries. When the CT value reached the threshold of 150~250 Hounsfield units(HU) at three consecutive sampling points, helical scanning was started automatically. Axial slices were reconstructed with a 1.25-mm slice thickness at 0.6-mm intervals. Images were processed using Advantage Workstation AW 4.0-04-sol7 (Sun-microsystem). The MIP images were produced by using window setting of 350 HU for center level and 1100 HU for window width. The VR images were produced by using 120-262 HU gradient value and 95% opacity. The setting values of reconstructions were fixed to reduce intra-operator variability. The image editing was done manually to remove any remaining bone of the cranial base. The MIP images were acquired every 7.5° while rotating through 180° in two plane and the VR images were acquired every 15° while rotating through 180° in two plane. Region of interest(ROIs) were established in the A1, M1, distal segment of the anterior cerebral artery (A2), and distal segment of the middle cerebral artery (M2) on each side. Initial MCTA was performed immediately in all patients who have aneurysmal SAH on initial head CT scan. After aneurysmal clipping, follow-up MCTA was performed to assess degree and distribution of cerebral vasospasm on MCTA in patients who were suspected to have symptomatic vasospasm and/or signs of vasospasm on TCD findings. Both initial and follow-up MCTA were performed in the exactly same manner. The initial and follow-up MCTA examinations were reviewed for presence of vasospasm by comparing corresponding vessel diameter on the initial and follow-up studies. The arterial diameters were measured by internal caliper tool. Degree of vasospasm on VR and MIP images was compared with the TCD values obtained within 24 hours of the MCTA. According to Newell's classification, vessels were classified as either basal or distal, dependent on the ability to be located by TCD[17]. The results were classified into four groups based on the distribution of vasospasm found on the MCTAs. Group 1 included patients who had less than 30% narrowing or no detectable narrowing between the initial and follow-up MCTA; Group 2 included patients who had significant spasm of the basal vessels only; Group 3 included patients who had significant spasm of basal and distal vessels; and Group 4 included patients who had significant spasm of distal vessels only without accompanying spasm of the basal vessels. To evaluate the accuracy of MCTA, we randomly selected 20 patients in whom postoperative three-dimensional(3D) DSA was performed and ROIs on initial MCTA images were compared with their postoperative 3D DSAs. VR technique was used for rendering of 3D DSA. The measurement of vessel diameter on 3D DSA was done using internal digital caliper.

Table 1. Demographic characteristics of all patients studies divided into DIND(+) and DIND(−) groups

Variables	Total(n=101)	DIND(+) (n=25)	DIND(−) (n=76)	p value (Chi-Square)
H-H grade, n(%)				
I	5	1(4%)	4(5.3%)	-
II	38	4(16%)	34(44.7%)	-
III	34	11(44%)	23(30.3%)	-
IV	22	8(32%)	14(18.4%)	-
V	2	1(4%)	1(1.3%)	0.111
Fisher grade, n(%)				
I	3	0(0%)	3(3.9%)	-
II	32	5(20.0%)	28(35.5%)	-
III	32	8(32%)	23(31.6%)	-
IV	34	12(48.0%)	22(28.9%)	0.217
Modified Fisher grade, n(%)				
I	17	1(4%)	16(21.1%)	-
II	19	3(12%)	16(21.1%)	-
III	65	21(84%)	44(57.9%)	0.048
Age, year, mean±SD	53.32±12.32	49±11.45	54.43±12.56	0.151
Sex, male, n(%)	41(40.5%)	11(44%)	30(39.4%)	0.815
SAH-OP, days, mean±SD	2.61±2.74	1.83±1.38	2.98±3.12	0.066
SAH-F/U MCTA, days, mean±SD	7.28±2.65	7.30±2.88	7.25±2.12	0.905
SAH-TCD, days, mean±SD	5.52±2.88	5.35±2.64	6.42±3.95	0.591
SAH-DIND, days, mean±SD		7.05±3.1		

DIND : delayed ischemic neurologic deficit, H-H : Hunt and Hess, SD : standard deviation, MCTA : multislice computerized tomographic angiography, op : operation, SAH : subarachnoid hemorrhage, TCD : transcranial doppler sonography, SAH-OP : timing of surgery after SAH onset, F/U : follow up, SAH-F/U MCTA : timing of follow-up MCTA after SAH onset, SAH-TCD : timing of positive TCD sign of vasospasm after SAH onset, SAH-DIND : timing of development of DIND after SAH onset

Table 2. Characteristics of 28 patients suspected of having vasospasm on TCD findings and clinical grounds

No	Sex/age	Location	H-H	F	MF	Time interval (day)				TCD* velocity(cm/s)				Diameter reduction percentages(VR/MIP)(%) on follow-up MCTA								DSA	GOS
						TCD	DIND	3H	MCTA f/u	Rt M1	Lt M1	Rt A1	Rt A1	Rt M_1	Lt M_1	Rt A_1	Lt A_1	Rt M_2	Rt M_2	Rt A_2	Rt A_2		
1	F/50	Rt AchA	3	3	3	9	14	9	13	140	130	45	85	32/22	40/34	50/39	47/25	40/35	0/0	43/24	56/24	+	GR
2	F/58	Lt MCA	4	4	3	3	9	3	6	68	147	55	60	0/0	0/0	20/17	56/45	0/0	0/5	0/0	0/5	+	SD
3	F/48	Rt PCOM	3	3	3	4	9	9	9	180	115	65	65	45/41	20/9	0/0	25/17	22/19	0/0	30/28	29/18	+	GR
4	F/45	Rt ICA	2	2	2	8	8	8	9	157	118	70	68	46/37	0/0	0/0	0/0	63/64	0/0	21/18	0/0	-	D
5	M/47	Lt PCOM	4	3	3	7	8	7	7	186	140	128	110	20/12	11/17	94/95	90/94	57/37	78/55	29/36	26/29	-	SD
6	M/30	Rt MCA	4	4	3	3	7	4	4	154	110	50	110	25/26	22/0	38/38	15/18	5/17	22/7	34/9	14/4	+	SD
7	F/47	ACOM	3	3	3	5	5	7	6	80	105	25	65	24/15	18/12	0/0	11/0	28/10	33/25	58/79	44/31	+	GR
8	F/48	ACOM	4	3	3	3	4	4	6	145	85	100	115	0/0	12/0	0/0	0/0	67/62	0/0	0/0	0/0	+	MD
9	M/53	Lt MCA	3	4	2	4	4	6	7	85	188	86	113	25/22	29/24	14/11	54/24	6/0	35/15	45/39	42/27	+	MR
10	M/37	ACOM	4	4	3	4	4	4	4	85	152	40	120	13/20	50/48	20/19	36/24	23/23	8/25	0/14	0/11	+	SD
11	M/60	ACOM	4	4	3	4	4	4	4	196	132	72	118	35/26	39/27	0/0	61/57	95/70	43/26	93/47	68/42	+	MD
12	M/35	Lt MCA	4	4	3	3	3	3	3	74	127	68	95	31/21	57/48	42/25	32/17	40/20	42/26	52/39	35/13	-	SD
13	F/46	Lt MCA	2	2	2	3	3	3	3	111	168	60	65	25/27	0/0	75/90	0/0	10/25	50/25	62/36	0/0	+	GR
14	M/47	Lt MCA	2	2	3	0	12	12	12	58	75	35	40	48/52	24/31	24/40	24/40	11/9	40/50	42/40	33/50	+	GR
15	F/65	ACOM	3	4	3	N	10	11	11	98	90	55	58	19/12	20/15	20/27	47/35	73/63	95/96	50/50	58/40	+	SD
16	F/38	Lt MCA	2	3	3	10	9	9	9	118	120	68	78	19/23	42/37	33/36	43/42	20/22	18/24	47/28	62/47	+	GR
17	F/60	ACOM	2	3	3	9	8	8	8	35	90	10	60	21/21	9/25	95/95	46/25	33/11	0/21	35/12	94/50	+	GR
18	F/72	Lt PCOM	3	4	3	N	7	9	9	25	25	U	U	20/20	12/7	50/36	7/21	0/8	0/0	29/33	75/92	-	SD
19	F/55	ACOM	2	3	3	9	7	7	7	62	75	55	50	7/0	3/3	0/0	0/11	0/0	14/10	50/40	50/32	+	MD
20	F/51	ACOM	5	3	3	N	4	4	4	49	42	30	32	0/8	32/28	0/0	50/41	11/19	0/21	0/0	31/20	-	VS
21	M/55	ACOM	2	4	3	6	N	7	6	102	128	42	48	20/27	29/20	60/58	50/34	25/34	15/27	54/50	54/58	+	GR
22	M/27	Rt MCA	2	4	3	4	N	5	5	150	60	35	30	59/54	14/13	22/0	26/18	7/3	11/3	28/4	11/13	+	GR
23	M/40	ACOM	2	3	3	4	N	12	7	110	145	53	98	22/0	11/0	55/43	0/0	5/0	0/0	10/22	0/0	+	GR
24	M/47	Lt AchA	2	2	2	4	N	7	8	80	176	75	85	5/0	53/58	0/0	43/53	17/0	43/26	9/0	20/0	+	GR
25	F/41	Rt MCA	2	2	3	11	N	13	12	150	85	50	65	71/58	21/25	36/23	0/0	35/24	0/0	21/5	0/6	+	GR
26	F/54	ACOM	2	3	3	13	N	6	6	82	77	108	77	0/0	0/0	34/33	30/5	4/11	17/0	57/56	47/30	+	GR
27	F/73	ACOM	2	4	3	N	N	6	7	30	40	U	U	13/12	17/10	0/0	0/0	5/8	4/4	19/17	0/0	-	MD
28	F/62	Rt PCOM	3	2	2	3	N	8	7	179	U	75	U	0/12	0/0	0/16	0/19	0/20	0/7	0/0	0/9	+	GR

TCD* : TCD which was performed within 24 hours of follow-up multislice computerized tomographic angiography(MCTA), H-H grade : Hunt and Hess grade, M : male, F : female, F : Fisher, MF : modified Fisher, TCD : transcranial doppler sonography, DIND : delayed ischemic neurologic deficit, MCTA : multislice CT angiography, DSA : digital subtraction angiography, GOS : Glasgow outcome scale, GR : good recovery, MD : moderate disability, SD : severe disability, VS : vegetative state, D : dead, AchA : anterior choroidal artery, MCA : middle cerebral artery, PCOM : posterior communicating artery, ICA : internal carotid artery, ACOM : anterior communicating artery, U : uncheckable, N : negative,- Rt : right, Lt : left, f/u : follow up

Table 3. Mean diameter and mean diameter difference on the initial MCTA and the post-operative DSA

	Mean diameter (mm)			Mean diameter difference(mm)			
	MIP*	DSA†	VR*	MIP*-DSA† difference	P value	VR*-DSA† difference	P value
Right M_1	2.48±0.40	2.33±0.32	2.18±0.40	0.15±0.31	0.133	-0.15±2.56	0.074
Left M_1	2.32±0.32	2.14±0.41	2.03±0.34	0.17±0.25	0.018	-0.12±0.20	0.034
Right A_1	1.90±0.47	1.59±0.51	1.41±0.47	0.31±0.33	0.011	-0.18±0.30	0.076
Left A_1	2.06±0.32	1.71±0.34	1.63±0.35	0.35±0.22	0.000	-0.06±0.19	0.262
Right M_2	2.08±0.37	1.99±0.37	1.80±0.43	0.09±0.31	0.29	-0.19±0.33	0.058
Left M_2	2.07±0.36	1.89±0.36	1.85±0.41	0.18±0.26	0.030	-0.05±0.24	0.505
Right A_2	1.82±0.38	1.54±0.44	1.40±0.49	0.27±0.29	0.009	-0.15±0.19	0.021
Left A_2	1.80±0.38	1.58±0.39	1.43±0.41	0.21±0.25	0.005	-0.16±0.18	0.005

MIP : maximum intensity projection, DSA : digital subtraction angiography, VR : volume rendering,- MCTA : multislice computerized tomographic angiography, * which was performed on initial admission, † which was performed just before discharge

Diagnosis of symptomatic vasospasm was based on the following criteria[26] : a) clinical deterioration in the patient's neurologic condition; b) exclusion of structural causes; c) absence of other identifiable causes of neurologic worsening such as serum electrolyte or glucose disturbances, hypoxia, hypercapnia, or seizures. TCD criteria for vasospasm was defined as daily increase > 50 cm/sec, Lindegaard ratio > 3 and mean cerebral blood flow velocity (MCBFV) of MCA > 120cm/sec.

Based on the clinical presentation of symptomatic vasospasm, we calculated the sensitivity, specificity, and positive and negative predictive values of TCD for vasospasm in the anterior cerebral circulation. We investigated the correlation between clinical, TCD, and MCTA signs of vasospasm. Analysis of the results was performed using a statistical pack-

Table 4. Mean diameters, mean reduction diameters and mean reduction percentages on each ROI of MCTA

	Mean diameter(mm)						Mean reduction diameter(mm)*				Mean reduction percentage of diameter(%)†		
	Intial			Vasospasm									
	VR	MIP	p value	VR	MIP	p value	VR	p value	MIP	p value	VR	MIP	p value
Rt M_1	2.23±0.42	2.50±0.37	.000	1.76±0.51	2.05±0.56	.000	0.47±0.56	0.000	0.44±0.55	.000	23.04±18.29	20.29±16.52	0.059
Lt M_1	2.19±0.44	2.46±0.42	.000	1.79±0.56	2.10±0.57	.000	0.39±0.45	0.000	0.36±0.51	.001	21.46±16.69	16.96±16.84	0.002
Rt A_1	1.21±0.68	1.58±0.80	.000	0.84±0.63	1.13±0.79	.000	0.37±0.50	0.001	0.45±0.63	.001	27.89±28.81	26.11±29.04	0.308
Lt A_1	1.28±0.57	1.56±0.57	.000	1.92±0.34	2.23±0.31	.000	0.44±0.51	0.000	0.44±0.50	.000	28.32±24.45	23.75±22.05	0.062
Rt M_2	1.43±0.57	1.75±0.52	.000	1.93±0.43	2.22±0.38	.000	0.49±0.54	0.000	0.41±0.51	.000	25.07±25.53	21.93±20.80	0.164
Lt M_2	1.59±0.64	1.89±0.64	.000	1.02±0.45	1.47±0.47	.000	0.34±0.55	0.003	0.33±0.53	.003	20.29±25.23	17.79±21.47	0.309
Rt A_2	1.44±0.47	1.86±0.33	.000	1.03±0.50	1.48±0.50	.000	0.44±0.48	0.000	0.41±0.47	.000	32.79±23.29	25.93±20.54	0.017
Lt A_2	1.72±0.44	2.00±0.43	.000	1.46±0.46	1.88±0.38	.000	0.41±0.51	0.000	0.38±0.45	.000	30.32±27.57	23.71±22.24	0.029

*, † We compared diameters of vessels on initial MCTA with the ones on follow up MCTA, MCTA : multislice computerized tomographic angiography, VR : volume rendering, MIP : maximum intensity projection, Rt : right, Lt : left, ROI : region of interest

Table 5. Distribution of vasospasm on MCTA

DIND	VR				MIP			
	(+)		(−)		(+)		(−)	
TCD Group	(+)	(−)	(+)	(−)	(+)	(−)	(+)	(−)
1	−	−	1	1	−	−	1	1
2	3	0	0	0	4	1	1	0
3	11	3	5	1	9	2	4	1
4	3	0	0	0	4	0	−	−

VR : volume rendering, MIP : maximum intensity projection, TCD : transcranial doppler, DIND : delayed ischemic neurologic deficit

age for the social sciences software (SPSS) (Ver11.5;,inc.,Chicago,IL). Categorical data were com-pared using the Chis-quare test and the Fisher exact test. The statistical significance of intergroup differences for continuous variables was assessed using the two sample t-test. Pearson's correlation analysis was used to evaluate the correlation of the diameter of vessel size and TCD and the comparisons of MIP and VR and DSA were done using the paired T test. We considered $p<0.05$ to be significant.

Results

Among 130 aneurysmal SAH patients, 101 patients met the inclusion criteria. The mean age of our patients was 53.32±12.32 years, and the 52 patients were male and 59 patients were female. The ruptured aneurysms were located on the ACA in 46 patients, the ICA in 34 patients, the MCA in 26 patients.

The mean time for symptomatic vasospasm presentation and TCD signs for vasospasm was 7.05±3.10 days and 5.00 ±2.90 days after SAH, respectively. Patients with symptomatic vasospasm had a significantly higher proportion of modified Fisher grade 3 on head CT scan on admission. There was no difference in the other variables analyzed (Table 1). We performed follow-up MCTA for the diagnosis of intracranial vasospasm following SAH in 28 patients suspected of having vasospasm on TCD findings and/or clinical grounds (Table 2). The mean time when the follow-up MCTA was performed for evaluation of vasospasm was 7.28±2.65 days after SAH. Symptomatic vasospasm developed in 25 patients (24.8%).

The overall sensitivity of TCD for anterior circulation in patients in symptomatic vasospasm was 84% with a specificity of 84.2%. Positive and negative predictive value of TCD to detect symptomatic vasospasm was 66.7% (22/33) and 95.6% (65/68), respectively. Three patients with symptomatic vasospasm had TCD signs of vasospasm after symptomatic vasospasm presentation. Another 3 patients with symptomatic vasospasm had no TCD sign of vasospasm in daily serial TCD recordings.

All initial MCTAs depicted no vasospasm except in one patient and postoperative 3D DSAs were performed in 77 patients before they were discharged. One hundred six ROIs on initial MCTA images were compared with their postoperative 3D DSAs. In any segment of measured vessels, mean diameter on MIP image was largest and mean diameter on VR image was smallest. In regard to mean diameter difference with 3D DSA, MIP image revealed discrepancies in 3 (left M1, both A1) of 4 proximal segments and in 3 (left M1, both A2) of 4 distal segments. VR image revealed discrepancies in 1 (Lt A1) of 4 proximal segments and in 2 (both A2) of 4 distal segments (Table 3).

Follow-up MCTA images for detecting vasospasm were not obtained in 5 patients among the 25 symptomatic vasospasm patients; two of them underwent DSA for endovascular treatment, one underwent MRA, one has ultra-early vasospasm and one in critically unstable state. The sensitivity of MCTA was 100%. On follow-up MCTA, VR and MIP image gave similar findings with regard to the reduction percentage of diameter except in the left M1 and the both A2 ($P<0.05$). The average of diameter reduction percentage on VR image was much large than ones on MIP image. Diameters of reduced vessels revealed on MIP images were significantly greater than

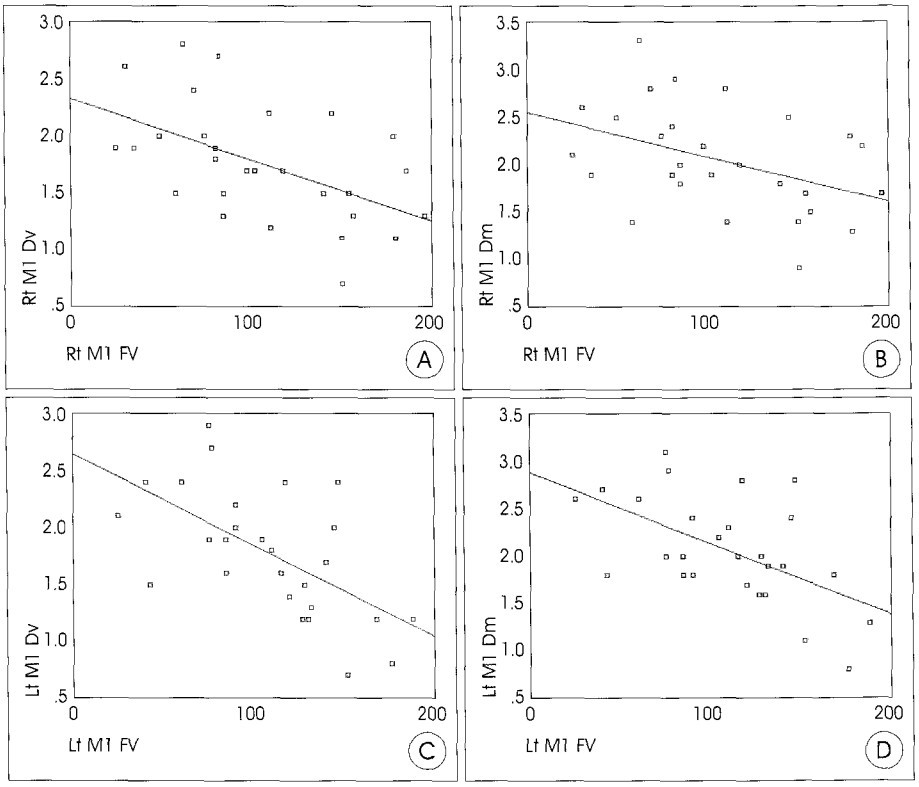

Fig. 1. Correlation between the transcranial doppler sonography(TCD) velocities and the vessel diameters of both M1. A : Right M1 diameter of VR(Rt M1 Dv) and right M1 TCD flow velocity(Rt M1 FV), R=−0.525 P=0.004. B : Right M1 diameter of MIP(Rt M1 Dm) and right M1 TCD flow velocity(Rt M1 FV), R=−0.420 P=0.026. C : Left M1 diameter of VR(Lt M1 Dv) and left M1 TCD flow velocity(Lt M1 FV), R=−0.601 P=0.001. D : Left M1 diameter of MIP(Lt M1 Dm) and left M1 TCD flow velocity(Lt M1 FV), R=−0.556 P=0.003. R : Pearson correlation coefficient, P : P value, VR : Volume rendering, MIP : maximum intensity projection.

those on VR images ($P<0.01$, Table 4). MCTA revealed vasospasm in the vessels of 26 patients. The MCTA showed false positive result in 6 patients, but these patients also had the TCD signs of vasospasm (Table 5). Three patients with vasospasm restricted to A2 or M2 had symptomatic vasospasm and these patients also had the TCD signs of vasospasm even though the A2 or M2 is outside the normal standard detection range. The MCBFV of both M1 was significantly correlated with each reduced M1 diameters on MCTA ($P<0.05$, Fig. 1). However, there were significant discrepancies between other MCTA findings and TCD values.

Discussion

The prevalence, definition, and diagnostic criteria for both angiographic and TCD signs of vasospasm vary among studies. Guidelines for optimal diagnostic

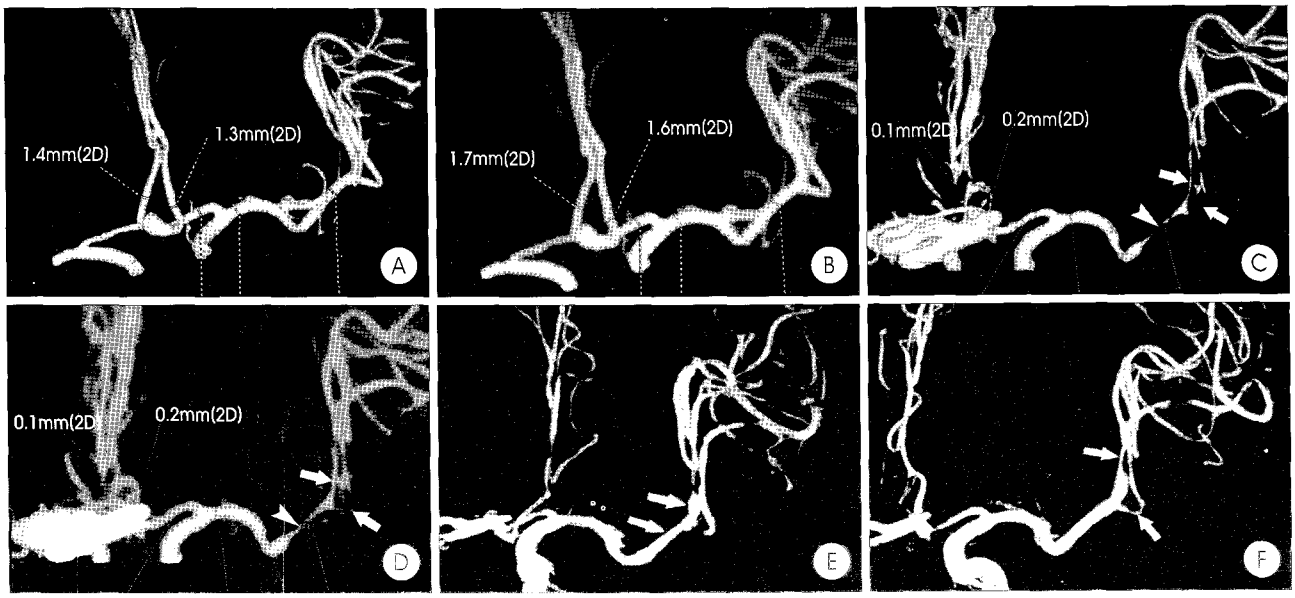

Fig. 2. A 65-year-old woman with vasospasm after aneurysmal subarachnoid hemorrhage(SAH). (left internal carotid artery anteroposterior view). A : Volume rendrering(VR) image and B : maximum intensity projection(MIP) image, initial multislice computerized tomographic angiography(MCTA) images revealing an anterior communicating artery aneurysm and there is no evidence of vasospasm on MCTA. C : VR image and D : MIP image, 10 days after onset of aneurysmal SAH, follow up MCTA revealing severe vasospasm on left M1(arrow head) and M2 artery vasospasm (arrows) and both anterior cerebral artery(ACA). E : 3-dimensional digital subtraction angiography(DSA) revealing improvement of vasospasm (arrows) on left M1 and a part of M2 after first endovascular treatment. F : 3-dimensional DSA revealing more improvement of vasospasm (arrows) on left M2 after second endovascular treatment.

algorithms have not yet been established, and various modalities have been examined for this purpose. But early identification of patients with aneurysmal SAH who are at high risk for symptomatic vasospasm is mandatory for following successful treatment of vasospasm. DSA is still the reference standard for demonstrating intracranial vasospasm, but it cannot be performed repeatedly in critically ill patients because of its invasive nature.

TCD is the commonly used method for the detection of cerebral vasospasm and several studies have shown good correlation between elevated MCBFV and angiographically documented vasospasm[11,14,26]. Despite this, there is still controversy regarding the value of TCD in every clinical practice[16]. Approximately 10% of studies in which TCD was used failed to detect signals of cerebral artery blood flow caused by poor insonation of the cranial window[13,30]. Elevated MCBFV reflect a physiologic phenomenon that may not necessarily be the result of narrowed vessel diameter[9]. If elevated MCBFV is due to cerebral hyperemia, the TCD may show a false positive result[7]. If very faint high-frequency or absent signal is emitted by profound narrowed vessel or tortuous or aberrant vessel[7,26] and if vasospasm occurs in the distal rather than the basal vessels which is outside the normal detection range of TCD[17] or increased intracranial pressure reduces flow velocity in spite of arterial narrowing[7,26], the TCD may show a false negative result and thus vasospasm may not be detectable by TCD. For these reasons, there is a need for a quantitative and non-invasive evaluation of vessel narrowing[4,17,18].

MCTA is quicker and provides clear vascular images, even of the peripheral arteries, than single detector CTA[5,19,31]. Because of the limited spatial resolution of single detector CTA, the distal segments of the cerebral arteries are poorly imaged[12,20]. Therefore, single detector CTA is less accurate for the detection of vasospasm in the distal segments of the cerebral arteries[1]. But Otawara et al have shown that MCTA can detect angiographic vasospasm after SAH with accuracy equal to that of DSA[19]. They have shown that MCTA could visualize the distal cerebral arteries, which resulted in a high percentage of agreement between DSA and MCTA for the detection of vasospasm after SAH. But they acquired only MIP image for evaluation of vasospasm.

The 3D-image of MCTA depends on both the reconstruction technique and the operator. There were several studies on MCTA, but their reconstruction techniques were not uniform, therefore the results can vary among studies. We used both VR and MIP technique for image reconstruction. MIP is a very popular and rapid technique and provides 2-dimensional image. But on MIP images, vessels running in front of or behind bony structures were obscured and evaluation of vasospasm near the skull base was problematic. The bones at the base of the skull were difficult to remove in the production processing of MIP images by using the threshold technique. So we had to remove the bones at the skull base manually. It took for 20~25 minutes to complete this work. Editing of MIP image was a tedious and time-consuming process. Presently, a lot of effort is being directed at further simplification of editing and automation of the measurement[22]. When we used the VR technique, bones at the base of the skull did not obscure the vessel and it supplied better morphological and anatomical information. Although this technique offers excellent images of the vessels, it requires a high power computer to handle the large volume of data and the diameter of intracranial vessels can be changed according to HU gradient and opacity value. So we fixed the setting values of all MCTA images to reduce intra-operator variability.

To evaluate the accuracy of MCTA, we compared initial MCTA images with their post-operative 3D DSAs. We used these as a reference value for the accuracy of MCTA even though it was thought to have some limitations and errors because this study was not performed in the same clinical condition[15,24]. If it is possible to perform MCTA and DSA simultaneously and then compare their results, it would be an ideal study. But it is undesirable to perform this method on critically ill patients for the purpose of study. In this study, the average diameters of all segments of the measured vessels on initial VR images were significantly smaller than those on initial MIP images but closer to those on post-operative 3D DSA. The proximal segments of both ACA and MCA on initial MCTA were closer to those on post-operative 3D DSA than the distal segments on initial MCTA.

We performed follow-up MCTAs in 28 patients. MCTA revealed vasospasm in the vessels of 26 patients. Among remaining 2 patients without MCTA evidence of vasospasm one patient who was thought to show neurologic deterioration due to vasospasm was due to a perforator injury and the other patient without neurologic deterioration had only TCD signs of vasospasm. The agreement between the diameters of the vessels on VR and MIP images of follow-up MCTA was statistically compared. The average diameters of all segments of the measured vessels on follow-up VR image were also significantly smaller than those on follow-up MIP image like the initial MCTA. Whereas, the average reduction percentages of segments of vessels on VR images were significantly similar with those on MIP images except in the left M1 and the both A2. MIP image could help differentiating atherosclerotic narrowing from vasospasm and the diameters of vessels on MIP were not influenced from changing HU gradient[1,5,22,32]. But the margin of narrowed vessel on MIP was unclear and blurred and it was difficult to measure severe arterial spasm accurately. VR image showed clear vascular margin than MIP

in vasospasm and did not need additional editing of removal of skull base bone[5,22,28]. But the diameters of vessels on VR image were influenced from changing HU gradient and diameter reduction percentage on VR image was much larger than the ones on MIP image. These findings suggest that VR image significantly tended to show more exaggerated vasospasm than MIP image.

Twenty five patients with significantly reduced diameters of vessels on follow-up MCTA fulfilled the TCD criteria for vasospasm. However individual analysis revealed that vessels which showed the highest velocity on TCD were not consistent with most narrowed vessels on follow-up MCTA. Correlation with the degree of vessel narrowing on MCTA and the degree of TCD signs of vasospasm was statistically studied. The MCBFV of M1 on TCD was significantly correlated with reduced each M1 diameters on MIP and VR image. But the MCBFV of TCD was not significantly correlated with reduced diameter percentage in any segment of vessels on MIP and VR image. Among the 26 patients with MCTA evidence of vasospasm, 3 patients had TCD signs of vasospasm after symptomatic vasospasm presentation. Another 3 patients with symptomatic vasospasm had no TCD signs of vasospasm in daily serial recordings. The reason why TCD failed to identify symptomatic vasospasm in our case is thought to be. One patient had vasospasm located mainly in both distal segment of MCA and ACA which was outside the standard detection range of TCD and very faint high velocity was emitted by profound narrowed vessels (Fig. 2). In the remaining 2 patients vasospasm was located in A1 and the sensitivity of TCD was thought to be cause of the missing vasospasm. In literature TCD is less sensitive for the spasm in other vessels except MCA because of their role as collateral channels or because of their difficult location[2,4,15,25]. In literature most patients with anterior circulation aneurysms who develop vasospasm will have involvement of the basal vessels, but a small number of patients may develop vasospasm only in distal vessels[4,17,27]. In our study, 3 patients with vasospasm evidence restricted to A2 or M2 on MCTA had symptomatic vasospasm but had also positive signs of TCD for vasospasm. Our study had the following limitations : First, reliability of MCTA for diagnosis of vasospasm is still questionable and a randomized-controlled trial is needed. Second, MCTA is unable to show dynamic characteristics of blood flow, such as cerebral circulating time. Third, visualization of the cerebral arteries requires intravenous injection of contrast medium, which may lead to preclude subsequent therapeutic angiography and intervention. Fourth, further simplification of editing and automation of the measurement are required. Fifth, in poor-grade patients with SAH, it was difficult to make an accurate diagnosis from signs of neurological deterioration because the neurological condition of these patients is already poor.

MCTA provided quantitative data on arterial spasm and location and distribution of vasospasm. Especially if the TCD signs for vasospasm are negative during the vasospasm risk period, MCTA should be considered in patients at high risk of vasospasm for noninvasive morphological study of vessel. It is possible that if the information gleaned from MCTA findings was used more often together with TCD findings in patient management, the outcome might be improved. MCTA scanners and software will be advanced in the future, the quality of the vascular images of MCTA will be improved with an even lower dose of contrast medium and MCTA would contribute significantly to establishing the diagnosis of vasospasm.

Conclusion

MCTA could be a useful tool for evaluation and planning management of critically ill patients suspected of having vasospasm; however, more randomized controlled trials are necessary to assess these points definitively.

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