INTRODUCTION

A duplicated middle cerebral artery (DMCA) is an anomalous vessel arising from the internal carotid artery (ICA). The origin of the DMCA lies between the anterior choroidal artery and the distal end of the ICA. Although there are several explanations for a duplicated middle cerebral artery (DMCA), its embryological origin is still an open question. Komiyama et al. proposed that the development of DMCA involves the anomalously early ramification of the early branches of the middle cerebral artery (MCA), based on their similarity to the cortical supply by the early branches of the MCA. Yamamoto et al. suggested that DMCA is a variant of the normal branching of the MCA. Kai et al. reported two types of DMCA: one with a course parallel to that of the main MCA (type A) and the other coursing toward the temporal lobe (type B).

We identified several DMCAs with conventional angiography, computed tomography (CT)-angiography, and magnetic resonance (MR)-angiography. We evaluated the courses of the DMCAs in the sylvian cistern with MR-angiography and analyzed the spatial relationships of the DMCAs with CT-angiography. We found that type A DMCAs had courses parallel to those of the other branch of the DMCA. The diameters of the type B DMCAs were the same, slightly smaller, or very much smaller than that of the other branch of the DMCA. Nine type B DMCAs showed parallel courses, and the other eight curved toward the temporal lobe.

MATERIALS AND METHODS

We retrospectively reviewed conventional cerebral angiograms to identify patients with DMCA. Conventional cerebral angiography (Philips V-3000, Philips Medical System, Eindhoven, Netherlands) was performed in 506 patients between April 1, 2000, and
Middle Cerebral Artery Duplication | HY Chang and MS Kim

September 30, 2006 at hospital A. In addition, conventional cerebral angiography (Philips V-5000) was also performed in 744 patients between July 1, 1997, and August 31, 2006, at hospital B.

We retrospectively reviewed the results of 2527 MR-angiographies performed between August 1, 2003, and December 31, 2007, in the hospital A to identify patients with DMCA. For the MR-angiography (1.5 T; Intera Achieva, Philips Medical System) studies, a three-dimensional time-of-flight (TOF) technique was used with a neurovascular phased array coil (SENSE-Head-8, Philips Medical System). A multiple-overlapping thin-slab acquisition technique was used. The following imaging parameters were selected: repetition time, 23 ms; echo time, 6.9 ms; field of view, 180×180 mm; number of slices, 120; slice thickness, 0.7 mm; slab thickness, 84 mm; imaging matrix, 384 ×512; number of excitations, 1. No intravenous paramagnetic contrast agent was administered to any of the patients. In each patient, a total of 20 maximum-intensity-projection images in the frontal view (both from left lateral to right lateral 180° and craniocaudally 180°) were routinely displayed stereoscopically.

We also retrospectively reviewed 1452 CT-angiographies that had been performed between January 1, 2009, and October 31, 2010, in the hospital A to identify patients with DMCA. CT-angiography was performed with a Toshiba CT scanner (Toshiba Aquilion TSX-101A 64 Channel; Toshiba Medical Systems, Tokyo, Japan). The following imaging parameters were selected: CT configuration, 64×0.5 mm; contrast amount, 100 mL of Iohexol (Iodox, Taejoo Pharmaceuticals Co. Ltd, Seoul, Korea) by automated antecubital venous infusion; contrast infusion rate, 2.0 mL/s; reconstructed section thickness and section interval, 5 mm with no interval; CT matrix, 512×512; 120 kilovolts (kVp); 100 milliamperes (mA); field of view, 64×64 mm.

The initial angiographic, CT-angiographic, and MR-angiographic studies were performed for a variety of clinical reasons, including symptoms of cerebral ischemia, hemorrhagic contusion, intracerebral hemorrhage, headache, dizziness, and routine check-up. In patients with DMCA, special attention was given to defining the origin, diameter, course, and spatial relationships with the structures surrounding the vessel.

We divided the DMCA into two types according to the classification of Kai et al. Type A DMCA originated from the top of the ICA, and type B DMCA separated between the top of the ICA and the anterior choroidal artery.

RESULTS

Twenty-five patients had 25 DMCA. Conventional angiography detected nine patients with DMCA (9/1250, 0.72%), MR-angiography detected seven patients with DMCA (7/2527, 0.28%), and CT-angiography detected nine patients with DMCA (9/1452, 0.62%). Eight patients had type A DMCA (Table 1), and 17 patients had type B DMCA (Table 2).

Table 1. Summary of eight patients with type A duplicated middle cerebral artery

| Case | Age/Sex | Course of DMCA | Site | Image | Dx | Size of DMCA |
|------|---------|----------------|------|-------|----|-------------|
| 1    | F/73    | Parallel       | RT   | MRA   | TIA| Same        |
| 2    | F/62    | Parallel       | LT   | MRA   | SAH, infarction | Same |
| 3    | M/70    | Parallel       | LT   | MRA   | Infarction | Slightly smaller |
| 4    | F/77    | Parallel       | LT   | TFCA  | SAH, infarction | Slightly smaller |
| 5    | M/28    | Parallel       | LT   | CTA   | Headache | Same |
| 6    | M/67    | Parallel       | LT   | CTA   | Chronic SDH | Slightly smaller |
| 7    | M/50    | Parallel       | RT   | CTA   | Cerebellar ICH | Slightly smaller |
| 8    | M/65    | Parallel       | RT   | CTA   | Cavernous sinus infection | Same |

DISCUSSION

Origin, size, and type of DMCA

According to the classification system proposed by Teal et
al.\textsuperscript{15}, the development of DMCA requires an anomalous MCA to arise from the distal ICA. Several authors have described the origin of the DMCA. Some groups have suggested that a DMCA originates from the ICA at the exact level of the end of the ICA or at the anterior choroidal artery\textsuperscript{6,17}. Other researchers have reported that the DMCA originates from the ICA between the anterior choroidal artery and the distal bifurcation of the ICA\textsuperscript{3,13}. Kai et al.\textsuperscript{9} divided DMCAs into two types according to their points of origin. Type A DMCAs originate from the top of the ICA, whereas type B DMCAs separate between the top of the ICA and the anterior choroidal artery.

There have been several reports of the sizes of DMCAs\textsuperscript{9,13,17}.

### Table 2. Summary of seventeen patients with type B duplicated middle cerebral artery

| Case | Age/Sex | Course of DMCA | Site | Image | Dx           | Size of DMCA |
|------|---------|----------------|------|-------|--------------|--------------|
| 9    | 47/F    | Curved         | RT   | TFCA  | Headache    | Same         |
| 10   | 59/F    | Curved         | LT   | TFCA  | SAH         | Slightly smaller |
| 11   | 52/M    | Curved         | RT   | TFCA  | Headache    | Much smaller |
| 12   | 54/F    | Parallel       | RT   | TFCA  | Headache    | Same         |
| 13   | 38/F    | Curved         | LT   | TFCA  | SAH         | Same         |
| 14   | 41/M    | Curved         | RT   | TFCA  | Headache    | Much smaller |
| 15   | 69/F    | Curved         | LT   | TFCA  | Infarction  | Slightly smaller |
| 16   | 59/F    | Parallel       | LT   | TFCA  | SAH         | Same         |
| 17   | 56/F    | Parallel       | RT   | CTA   | Headache    | Slightly smaller |
| 18   | 33/F    | Parallel       | LT   | CTA   | Headache    | Much smaller |
| 19   | 54/M    | Parallel       | RT   | CTA   | 3rd nerve palsy | Much smaller |
| 20   | 55/F    | Curved         | RT   | CTA   | Headache    | Much smaller |
| 21   | 87/M    | Parallel       | LT   | CTA   | Infarction  | Same         |
| 22   | 54/F    | Parallel       | RT   | MRA   | Chronic sinusitis | Slightly smaller |
| 23   | 41/M    | Parallel       | LT   | MRA   | Headache    | Much smaller |
| 24   | 54/F    | Curved         | LT   | MRA   | Headache    | Much smaller |
| 25   | 58/M    | Parallel       | LT   | MRA   | TIA         | Same         |

Parallel: parallel course with another duplicated middle cerebral artery. Curved: curved course to temporal lobe. SAH: subarachnoid hemorrhage. TIA: transient ischemic attack. DMCA: duplicated middle cerebral artery. Dx: diagnosis. RT: right. LT: left. MRA: magnetic resonance angiography. CTA: computed tomography angiography. TFCA: trans femoral cerebral angiography. Size of DMCA: relative size compared with diameter of the other branches of the DMCA.
Umansky et al.\textsuperscript{17} reported that the DMCA and the main MCA trunk had the same outer diameter (3.5 mm). In contrast, Komiyama et al.\textsuperscript{13} proposed that the DMCA diameter is smaller than that of the main MCA trunk. Kai et al.\textsuperscript{9} divided these vessels into two groups according to their diameter relative to that of the main MCA. The diameter of the type A DMCA is the same as that of the main trunk of the MCA, whereas the diameter of the type B DMCA is smaller than that of the main MCA. In our study, we found that the diameter of the type A DMCA was the same or slightly smaller than that of the other branch of the DMCA. However, the type B DMCA had a diameter that was the same as, slightly smaller than, or very much smaller than that of the other branch of the DMCA.

There are two theories regarding the cortical territory and course of DMCA. One theory maintains that the DMCA can be regarded as an early temporal branch of the MCA\textsuperscript{1,13}. Komiyama et al.\textsuperscript{13} reported that the DMCA in their series consistently reached the temporopolar and anterior and/or middle temporal territories. In these reports, the DMCA were similar to the anterior temporal arteries. Nomura et al.\textsuperscript{2} and Choi et al.\textsuperscript{14} considered DMCA to be the early bifurcation of the anterior temporal artery. Gibo et al.\textsuperscript{6} also suggested that DMCA are distributed to the temporopolar area and the anterior and middle temporal areas.

A second theory maintains that the DMCA arises as the direct bifurcation of the main trunk of the MCA. Yamamoto et al.\textsuperscript{18} defined the DMCA as a ‘direct bifurcation’ because this anomalous artery branches directly from the ICA. Kai et al.\textsuperscript{9} noted that the type A DMCA separates at the top of the ICA, giving the impression of an early bifurcation. This type A DMCA may arise from the direct bifurcation of the MCA because the anomalous artery branches directly from the ICA. Conversely, the type B DMCA is an anomalously early manifestation of an MCA branch.

In our study, all type A DMCA showed a course parallel to that of the other branch of the DMCA. Nine type B DMCA showed a course parallel to that of the other branch, whereas the other eight type B DMCA had a curved course toward the temporal lobe. In our study, all type A and type B DMCA with a parallel course could be regarded as direct bifurcations of the MCA trunk. The type B DMCA with a curved course toward the temporal lobe can be regarded as an early temporal branch of the MCA.

Clinical significance
DMCA themselves have no clinical significance. However, rare aneurysms have been reported at the origin of the DMCA\textsuperscript{2,5,7,10-12}. It is unclear whether this association is a chance occurrence or related by an unknown mechanism. Kai et al.\textsuperscript{9} reported that all aneurysms associated with DMCA were found at the origins of type B DMCA. They insisted that type B DMCA can be expected to be subject to higher hemodynamic stress and that this is a factor in the development of aneurysms on the type B DMCA.

We also reviewed all DMCA associated with aneurysms originating at the origin of a DMCA\textsuperscript{2,9-11}. In most of these cases, the DMCA were type B. However, one aneurysm associated with a DMCA arose from the trunk of the DMCA\textsuperscript{16}. Another aneurysm was associated with a type A DMCA\textsuperscript{12}. Contrary to the description of Kai et al.\textsuperscript{9}, type B DMCA can be divided into two types. One type has a course parallel to that of the other branch of the DMCA, and the second type has a course that curves toward the temporal lobe. Only DMCA with a sharply curved course to the temporal lobe were associated with aneurysms originating from the origin of this vessel.

The identification of anomalously early manifestations of the MCA is important for the surgical dissection of cerebral aneurysms associated with DMCA. Because the DMCA may contribute to the normal cerebral blood supply, care should be taken not to damage this vessel during surgery. If the aneurysm
arises between the two M2 vessels originating at the carotid terminal site, the medial lenticulostriate perforators may be in close proximity and must be protected during dissection and clipping. The DMCA may also play an important role in supplying collateral blood flow to the frontal lobe and basal ganglia through the perforating arteries. However, it does not seem to supply significant flow to the main MCA territory. In cerebral infarction with stenosis or occlusion of only one branch of the DMCA, MR-angiography might appear similar to those produced by the normal condition, as in patient 3 in our study (Fig. 2). This MR-angiography image may be produced in one of two ways. First, the image may be the result of adequate collateral flow from the other branch of the DMCA, when there is stenosis or occlusion of one branch of the DMCA. The second possibility is that this image results from poor resolution on MR-angiography of the flow in the superior division of the DMCA. Under conditions of suspected cerebral infarction, we must consider this kind of MCA variation in interpreting the results of MR-angiography.

**CONCLUSION**

Type A DMCA has a course parallel to that of the other branch of the DMCA and a similar diameter, and can be regarded as an early bifurcation of the MCA. The type B DMCA with a temporal course can be regarded as an early temporal branch of the MCA. Although all DMCA were found incidentally in this study, some clinical implications were found in literature review and in this study. Most DMCAs associated with aneurysms of the MCA showed type B DMCA with a temporal course. When cerebral infarction involving the MCA is suspected, we should consider this DMCA in interpreting MR-angiographic images.

**Acknowledgements**

This work was supported by research grant from an Inje University College of Medicine.

**References**

1. Abanou A, Lasjaunias P, Manelle C, Lopez-Ibor I : The accessory middle cerebral artery (AMCA). Diagnostic and therapeutic consequences. *Anat Clin* 6 : 305-309, 1984
2. Choi JW, Joo SP, Lee JK, Kim TS : Middle cerebral artery variations. Associated with intracranial aneurysmal rupture. *J Korean Neurosurg Soc* 39 : 467-470, 2006
3. Crompton MR : The pathology of ruptured middle-cerebral aneurysms with special reference to the differences between the sexes. *Lancet* 2 : 421-425, 1962
4. Dong LW, Yamada K, Ohta T, Takahashi N : [Ruptured intracranial aneurysm combined with multiple cerebral vessel anomalies; a case report.] No Shinkei Geka 19 : 975-978, 1991
5. Fuwa I, Matsu kado Y, Wada H : [Intracranial aneurysms associated with the accessory middle cerebral artery and duplication of the middle cerebral artery. Report of two cases.] *Neurol Med Chir (Tokyo)* 24 : 207-211, 1984
6. Gibo H, Carver CC, Rhoton AL Jr, Lenkey C, Mitchell RJ : Microsurgical anatomy of the middle cerebral artery. *J Neurosurg* 54 : 151-169, 1981
7. Imazumi S, Onuma T, Motohashi O, Kameyama M, Ishii K : Unruptured carotid-duplicated middle cerebral artery aneurysm : case report. *Surg Neurol* 58 : 322-324, 2002
8. In S, In K, Kusano N, Mizuki H, Miyagi I, Kuramoto S : [A case of duplication of the middle cerebral artery with ruptured aneurysm on its origin during pregnancy (author's trans.).] No Shinkei Geka 9 : 337-341, 1981
9. Kai Y, Hamada I, Moritsuka M, Yano S, Kudo M, Kuratsu J : Treatment of unruptured duplicated middle cerebral artery aneurysm : case report. *Surg Neurol* 65 : 190-193, discussion 193, 2006
10. Kalaperumal C, Jain N, McKinstry CS, Choudhari KA : Carotid "trifurcation" aneurysm : surgical anatomy and management. *Clin Neurol Neurosurg* 109 : 538-540, 2007
11. Kang SD, Kim JM : An aneurysm arising at the site of the middle cerebral artery duplication. *J Korean Neurosurg Soc* 25 : 1318-1322, 1996
12. Kitami K, Kam i yama H, Yasui N : [Angiographic analysis of the middle cerebral artery in cerebral aneurysms--its branching pattern and so-called vascular anomalies.] No Shinkei Geka 13 : 283-290, 1985
13. Komiyama M, Nakajima H, Nishikawa M, Yasui T : Middle cerebral artery variations: duplicated and accessory arteries. *AJNR Am J Neuroradiol* 19 : 45-49, 1998
14. Nomura M, Yamashima T, Kita D, Kida S, Kajinami K, Yamashita J : Duplication of the middle cerebral artery associated with an unruptured aneurysm. *Acta Neurochir (Wien)* 142 : 221-222, 2000
15. Teal JS, Rumbaugh CL, Bergeron RT, Segall HD : Anomalies of the middle cerebral artery : accessory artery, duplication, and early bifurcation. *Am J Roentgenol Radium Ther Nucl Med* 118 : 567-575, 1973
16. Uchino M, Kitajima S, Sakata Y, Honda M, Shibata I : Ruptured aneurysm at a duplicated middle cerebral artery with accessory middle cerebral artery. *Acta Neurochir (Wien)* 146 : 1373-1374; discussion 1375, 2004
17. Umansky F, Dujovny M, Ausman JI, Diaz FG, Mirchandani HG : Anomalies and variations of the middle cerebral artery : a microanatomical study. *Neurosurgery* 22 : 1023-1027, 1988
18. Yamamoto H, Marubayashi T, Soejima T, Matsuoka S, Matsu kado Y, Ushio Y : Accessory middle cerebral artery and duplication of middle cerebral artery--terminology, incidence, vascular etiology, and developmental significance. *Neurol Med Chir (Tokyo)* 32 : 262-267, 1992