Fenestrations of the Basilar Artery Demonstrated on Magnetic Resonance Angiograms: an Analysis of 212 Cases

KEIJI SOGAWA¹, YOICHI KIKUCHI¹, TOSHIHIRO O'UCHI¹, MICHIIHIRO TANAKA¹, TOMIO INOUE²

¹ Kameda Medical Center; Kamogawa City, Chiba, Japan

² Yokohama City University Graduate School of Medicine; Yokohama City, Japan

Key words: basilar artery, fenestration, MR angiography, normal variant

Summary

Fenestration of the basilar artery (BA) is a rare variant of the intracranial artery, well demonstrated in autopsy and angiographic studies. Some angiographic series show a high incidence of associated aneurysms at the basilar fenestration site. The purpose of this study is to report the incidence of BA fenestration, its configurations, associated aneurysms, and arterial anomalies in a large series of intracranial MR angiograms (MRAs).

A total of 16,416 MRAs were retrospectively reviewed to identify the location, size and associated intracranial arterial anomalies of BA fenestrations. All images were obtained with the time-of-flight (TOF) technique. Of the 16,416 MRAs, 215 fenestrations were found in 212 cases (1.29%). Most fenestrations were located in the proximal BA. The average length of the fenestration was 4.6 mm; the largest was 15.6 mm. No aneurysm was found at the site of the fenestration. Thirteen aneurysms were found in nine cases at locations other than the BA: seven in the middle cerebral artery (MCA), one in the anterior cerebral artery (ACA), one in the anterior communicating artery (Acom), one in the vertebral artery (VA), one at the carotid siphon, and two at the internal carotid-posterior communicating artery (IC-PC). Arterial anomalies in other locations were found in 26 cases.

BA fenestrations were found in 1.29% of the 16,416 cases studied. There were no aneurysms at the BA fenestration site. Aneurysms at the BA fenestration site may be an exceedingly rare phenomenon.

Introduction

The basilar artery (BA) is formed by a fusion of the primitive longitudinal neural arteries by approximately the fifth fetal week. BA fenestrations result from incomplete fusion of these arteries¹, and are more common in the proximal segment of the BA¹⁻⁴. The term fenestration has been used interchangeably with partial duplication or segmental duplication. Most fenestrations are smaller than 5 mm in length^{5,6}. The frequency of BA fenestrations has been found to be 0.28%-5.26% in autopsy series⁷⁻¹⁰, 0.3%-0.6% in angiographic series^{11,12} and 1.0% - 2.07% in magnetic resonance angiography (MRA) series¹³⁻¹⁵. Saccular aneurysms are occasionally found at the BA fenestration site^{2,14,16-23}. This study reports the incidence of BA fenestrations, their configurations, associated aneurysms, and arterial anomalies in a large series of intracranial MR angiograms.

Materials and Methods

A waiver of informed consent was granted by our institutional review board because of the retrospective and anonymous nature of this study. At our institution, MRAs are generally performed in all cases whenever brain magnetic resonance imaging (MRI) is ordered. Between April 2008 and March 2011, non-contrast MRAs with 3D time-of-flight (TOF) technique were performed in 16,471 cases (8,621 males; 7,850 females) for various indications. A total of 55 cases were excluded: those that had suboptimal

Figure 1 A 19-year-old man presented with headache. MR angiogram of the VB system shows double separate fenestrations (arrows), one fenestration in the distal segment and the other in the proximal segment.

Figure 2 A 63-year-old man presented with dizziness. MR angiogram of the VB system shows double adjacent fenestrations (arrow) in the proximal segment.

image quality, occlusion of the BA or if the entire BA was not visualized. “Dimple”-like configurations that were not considered fenestrations were excluded from BA fenestration cases. A total of 16,416 cases (8,595 males; 7,821 females) aged one to 100 years were included in this study.

The MRI scanners and imaging parameters were GE Signa Excite 1.5T scanner (GE Health Care, Milwaukee, USA) TR 28.0~34.0 ms, TE 3.4~6.3 ms, FOV 200×200 mm, matrix 256×160, slab thickness 96 mm, reconstructed slice thickness 1.2 mm; Siemens Avanto 1.5T scanner (Siemens Medical Solutions, Erlangen, Germany) TR 34.0 ms, TE 6.8 ms, FOV 210×189 mm, matrix 320×187, slab thickness 96 mm, reconstructed slice thickness 0.95 mm; and Siemens Magnetom Expert 1.0T scanner (Siemens Medical Solutions, Erlangen, Germany) TR 37.0 ms, TE 10.9 ms, FOV 150×200 mm, matrix 195×320, slab thickness 92 mm, reconstructed slice thickness 2 mm. Twelve pairs of stereoscopic MRA images with maximum intensity projection (MIP) technique in 16,416 cases were reviewed by a third year resident (KS), using 9-Mb monitors (IBM). When fenestrations were detected, a staff neuroradiologist (TO) with 25 years experience of inter-

preting MRA evaluated and confirmed the findings. If more than one MRA was performed on the same patient over the course of three years, the best quality MRA was evaluated for the study. We recorded location and the distance from the proximal to distal end of the BA fenestration, associated aneurysms and arterial anomalies.

Results

Among 16,416 cases, 215 BA fenestrations were found in 212 cases (1.29%). The average age of the cases was 63.7 years, and there were 108 men and 104 women. Only three BA fenestrations were located at the distal segment of the BA, and 209 were located at the proximal segment. The average length of fenestration was 4.6 mm (1.6 mm-15.6 mm). All the BA fenestrations were segmental type. There was no case of *fenestration of the entire segment of the BA* in this series. Single fenestrations were found in 209 of 212 cases. The total frequency of the single fenestration was 1.27% (209/16416). Double fenestrations were found in three of 212 cases. One case had separate fenestrations in the distal and proximal seg-

ment of the BA (Figure 1). The other two cases had adjacent fenestrations in the proximal segment (Figure 2). And total frequency of the double fenestration was 0.018% (3/16416). Thirteen aneurysms were found in nine fenestration cases. All the aneurysms were located outside the BA fenestration site. The number and locations of these 13 aneurysms were seven in the MCA, one in the ACA, one in the Acom, two in the IC-PC, one in the ICA siphon, and one in the VA. Associated vascular anomalies were found in 25 cases: one VA fenestration, three ACA fenestrations, one common anterior inferior cerebellar artery-posterior inferior cerebellar artery, three azygos ACAs, four triple ACAs, two duplication of MCAs, and 11 accessory MCAs.

Discussion

Although previous studies have shown associated aneurysms at the basilar artery (BA) fenestration site, most studies were from angiographic series in symptomatic cases with subarachnoid hemorrhage. Our study of a large number of MRAs showed no associated aneurysms at the BA fenestration site.

BA Fenestration

The BA is formed by fusion of the *paired* longitudinal neural arteries at the 4 to 5 mm embryo during its first stage. During the second stage of development at five week's gestation, fusion of the channels gradually starts to form the BA. BA fenestrations result from incomplete fusion of these arteries¹, and may occur anywhere along its course. Most BA fenestrations, however, were located at the proximal segment in previous reports¹⁻⁴. All the BA fenestrations in our study were located at the proximal segment of the BA except for three cases. The fusion usually occurs in a craniocaudal direction. This craniocaudal direction may underlie the frequent fenestration of the BA at its proximal segment¹⁵.

Various configurations of the fenestration have been described using several terms. Fenestration of the entire segment of the BA has been called "duplication"^{24,25}, "total duplication"^{13,26}, "complete fenestration"¹¹, "complete duplication"^{3,15,16,27,28} and "extreme fenestration"^{26,27}. Fenestration of the short segment of the BA has been termed "fenestration"^{16,26},

"partial fenestration"¹¹, "partial duplication"^{27,28}, "segmental duplication"^{2,3,16,17,25,26,28} and "localized duplication"^{6,25}. The BA is formed by fusion of the paired longitudinal neural arteries during development. *Therefore it is probably more appropriate to use the term "segmentally unfused arteries" to refer this anatomical variant*²⁹. All the BA fenestrations we found were short segment configuration.

Previous studies have shown that the prevalence of the BA fenestrations was 0.28%-5.26%⁷⁻¹⁰ in anatomic dissections, 0.3%-0.6% in angiographic series^{11,12} and 1.0%-2.07% in MRA series¹³⁻¹⁵. In our study, the prevalence of BA fenestration was 1.29% (212/16416) which is higher than those in angiographic series. The discrepancy between the prevalences of angiographic series and MRA series could be explained by obscuration of BA fenestration on selective vertebral angiograms by laminar flow from the contralateral VA¹³.

In an MRA study by Tanaka et al., the average size of BA fenestration was 2.4 mm¹⁴. In Finlay and Canham's autopsy series, fenestrations were relatively small, with the largest one approximately 5 mm long⁵. Campos et al. reported the length of the BA fenestration in 21 cases with angiogram. In six cases, the length of the fenestration measured less than 5 mm; in 14 cases it measured 6-10 mm; and in one case it was 15 mm¹⁶. In our study, the average length of the fenestration was 4.6 mm. The largest one was 15.6 mm. Since it is a two-dimensional measurement from the frontal view of an MIP image, there is a possibility that underestimations of the length were made in some cases.

In our study, fenestration of the entire segment of the BA was not found. Many authors reported *this configuration of the BA fenestration*^{6,11,26,27}, with its frequency of 0.3%⁶. Our result suggests that the frequency of complete fenestration is probably lower than 0.006% (1/16,416). BA fenestration is usually single but a case with multiple fenestrations of the vertebrobasilar system has been reported³⁰. In our study, 209 of 212 cases of BA fenestrations were single fenestrations, double fenestrations were found in three cases. Thus, the prevalence of single fenestration was 1.27% (209/16,416), and that of double fenestrations was 0.018% (3/16,416). This is very close to the square of the prevalence of single fenestration ($[0.0127]^2=0.016\%$), suggesting that each occurrence of the BA fenestration is an independent phenomenon.

Associated Aneurysm

There have been many reports of saccular aneurysms associated with the BA fenestrations^{2,14,16-23}. Most of these aneurysms were located at the proximal end of the BA fenestration. Aneurysms at the distal end of the fenestration were rare¹⁷. Hemodynamic stress and absence of the media at the fenestration are thought to be the cause of aneurysm formation^{2,16,31,32}.

The incidence of aneurysm at the BA fenestration was 7.0%-66.7% in angiographic studies^{12,22,33}. However, there is one report that showed BA fenestrations were not related to the occurrence of aneurysms¹¹.

To the best of our knowledge, our study is the largest series of BA fenestration demonstrated on MRA. Our series showed no aneurysm at the BA fenestration site. Only two of the 212 cases had a history of subarachnoid haemorrhage (SAH) due to ruptured aneurysm outside the BA.

Our study of 16,416 MRAs is probably a better reflection of the prevalence of BA fenestrations and associated aneurysms in the general population than the previous angiographic studies that were done in mostly symptomatic cases^{2,17-23}. Tasker et al. reported nine cases of BA fenestration on angiograms. In six cases, the aneurysms arose at the site of BA fenestration. Five cases out of six BA fenestration cases presented with SAH, and the other case of BA fenestration was found as an incidental finding²². Our result suggests that BA fenestrations are not frequently associated with aneurysm formations at the BA fenestration site in cases that underwent MRA for reasons other than SAH. This could explain the discrepancy between the high incidence of aneurysms at BA fenestration in previous reports and our result of no association of aneurysms.

Associated Vascular Variant

BA fenestration associated with persistent primitive trigeminal artery^{34,35} and persistent primitive hypoglossal artery⁴ are reported. We did not find these anomalies in our cases.

Limitations

Our study has some limitations. Although it is reported that MRA with the volume rendering technique is better than that with the MIP reconstruction technique to detect small aneurysms³⁶, this technique was not available and was not used in our study. During the early phase of our study, some MRAs were performed on 1.0T unit which has less spatial resolution than that of 1.5T unit. This might have led smaller aneurysms to be missed.

A previous study showed that contrast-enhanced MRA had a higher sensitivity in the depiction of cerebral aneurysms than non-contrast 3D-TOF technique³⁷. It is also reported that 3D CT angiography (CTA) is less reliable for ruling out the presence of aneurysm than digital subtraction angiography (DSA)³⁸. Contrast-enhanced MRA, 3D CTA and DSA have better capabilities for delineating small aneurysms than non-contrast MRA with 3D-TOF technique. However, these are not suitable for studying asymptomatic patients or screening.

MRA on higher magnetic field strength imager with 3D reconstruction technique may depict smaller aneurysms at the BA fenestration. The long-term follow-up of these 212 cases with BA fenestrations using these high resolution MRAs may contribute to the study of the natural history of BA fenestration in relation to aneurysm formation.

Conclusion

Fenestration of the BA is uncommonly seen on intracranial MRA. Although previous reports have stated that this anatomical variant is frequently associated with aneurysm, our study of a large number of MRAs suggests that aneurysms may not be associated with BA fenestrations with a high frequency.

Acknowledgment

We thank Sandra Y. Moody M.D. for her assistance in manuscript preparation.

References

- 1 Padgett DH. The development of the cranial arteries in the human embryo. *Contrib Embryol*. 1948; 32: 205-261.
- 2 Black SP, Ansbacher LE. Saccular aneurysm associated with segmental duplication of the basilar artery. A morphological study. *J Neurosurg*. 1984; 61 (6): 1005-1008.
- 3 De Caro R, Serafini MT, Galli S, et al. Anatomy of segmental duplication in the human basilar artery. Possible site of aneurysm formation. *Clin Neuropathol*. 1995; 14 (6): 303-309.
- 4 Kanematsu M, Satoh K, Nakajima N, et al. Ruptured aneurysm arising from a basilar artery fenestration and associated with a persistent primitive hypoglossal artery. Case report and review of the literature. *J Neurosurg*. 2004; 101 (3): 532-535.
- 5 Finlay HM, Canham PB. The layered fabric of cerebral artery fenestrations. *Stroke*. 1994; 25 (9): 1799-1806.
- 6 Takahashi M. The basilar artery. In: Newton TH, Potts DG, eds. *Radiology of the Skull and Brain Angiography*. Vol 2, book 2. St Louis, The CV Mosby Co.; 1974. pp 1775-1795.
- 7 Wollschlaeger G, Wollschlaeger PB, Lucas FV, et al. Experience and result with post-mortem cerebral angiography performed as routine procedure of the autopsy. *Am J Roentgenol Radium Ther Nucl Med*. 1967; 101 (1): 68-87.
- 8 Stopford JSB. The arteries of the pons and medulla oblongata. *J Anat*. 1916; 50: 132-164.
- 9 Busch W. Beitrag zur Morphologie und Pathologie der Arteria Basialis (Untersuchungsergebnisse bei 1000 Gehirnen). [Contribution to the morphology and pathology of the basilar artery. Results of the study of 1000 brains]. *Arch Psychiatr Nervenkr*. 1966; 208 (4): 326-344.
- 10 von Mittelwallner F. Variationsstatistische Untersuchungen an den basalen Hirngefassen. [Statistical studies on variations of the basal cerebral vessels]. *Acta Anat (Basel)*. 1955; 24 (1): 51-87.
- 11 Takahashi M, Tamakawa Y, Kishikawa T, et al. Fenestration of the basilar artery. *Radiology*. 1973; 109 (1): 79-82.
- 12 Sanders WP, Sorek PA, Mehta BA. Fenestration of intracranial arteries with special attention to associated aneurysms and other anomalies. *Am J Neuroradiol*. 1993; 14 (3): 675-680.
- 13 Uchino A, Kato A, Takase Y, et al. Basilar artery fenestrations detected by MR angiography. *Radiat Med*. 2001; 19 (2): 71-74.
- 14 Tanaka M, Kikuchi Y, Ouchi T. Neuroradiological analysis of 23 cases of basilar artery fenestration based on 2280 cases of MR angiographies. *Interv Neuroradiol*. 2006; 12 (Suppl 1): 39-44.
- 15 Uchino A, Saito N, Okada Y, et al. Fenestrations of the intracranial vertebrobasilar system diagnosed by MR angiography. *Neuroradiology*. 2012; 54: 445-450.
- 16 Campos J, Fox AJ, Viñuela F, et al. Saccular aneurysms in basilar artery fenestration. *Am J Neuroradiol*. 1987; 8 (2): 233-236.
- 17 Andrews BT, Brant-Zawadzki M, Wilson CB. Variant aneurysms of the fenestrated basilar artery. *Neurosurgery*. 1986; 18 (2): 204-207.
- 18 Hoffman WF, Wilson CB. Fenestrated basilar artery with an associated saccular aneurysm: case report. *J Neurosurg*. 1979; 50 (2): 262-264.
- 19 Crivelli G, Bianchi M, Dario A, et al. Saccular aneurysm associated with proximal basilar artery fenestration. Case report. *J Neurosurg Sci*. 1993; 37 (1): 29-34.
- 20 Becker DH, Hamilton RD. Saccular aneurysm associated with fenestrated basilar artery: Case report. *Neurosurgery*. 1979; 5 (6): 695-697.
- 21 Foroni LH, Figueiredo EG, et al. Saccular aneurysms at middle basilar trunk fenestration. *Arq Neuropsiquiatr*. 2010; 68 (2): 309-311.
- 22 Tasker AD, Byrne JV. Basilar artery fenestration in association with aneurysms of the posterior cerebral circulation. *Neuroradiology*. 1997; 39 (3): 185-189.
- 23 Hemmati M, Kim KS. A ruptured aneurysm at the basilar artery fenestration. *Radiology*. 1979; 130 (1): 174.
- 24 Handa J, Teraura T, Imai T, et al. Agenesis of the corpus callosum associated with multiple developmental anomalies of the cerebral arteries. *Radiology*. 1969; 92 (6): 1301-1304.
- 25 Cademartiri F, Stojanov D, Dippel DW, et al. Noninvasive detection of a ruptured aneurysm at a basilar artery fenestration with submillimeter multislice CT angiography. *Am J Neuroradiol*. 2003; 24 (10): 2009-2010.
- 26 Uchino A, Sawada A, Takase Y, et al. Extreme fenestration of the basilar artery associated with cleft palate, nasopharyngeal mature teratoma, and hypophyseal duplication. *Eur Radiol*. 2002; 12 (8): 2087-2090.
- 27 Goldstein JH, Woodcock R, Do HM, et al. Complete duplication or extreme fenestration of the basilar artery. *Am J Neuroradiol*. 1999; 20 (1): 149-150.
- 28 Berry AD III, Kepes JJ, Wetzel MD. Segmental duplication of the basilar artery with thrombosis. *Stroke*. 1988; 19 (2): 256-260.
- 29 Krings T, Baccin CE, Alvarez H, et al. Segmental unfused basilar artery with kissing aneurysms: report of three cases and literature review. *Acta Neurochir (Wien)*. 2007; 149 (6): 567-574.
- 30 Fujimura M, Sugawara T, Higuchi H, et al. A ruptured aneurysm at the distal end of the basilar artery fenestration associated with multiple fenestrations of the vertebrobasilar system: Case report. *Surg Neurology*. 1997; 47 (5): 469-472.
- 31 Ferguson GG. Physical factors in initiation, growth and rupture of human intracranial saccular aneurysms. *J Neurosurg*. 1972; 37 (6): 666-677.
- 32 Crompton MR. The pathology of ruptured middle-cerebral aneurysms with special reference to the differences between the sexes. *Lancet*. 1962; 2 (7253): 421-425.
- 33 Yock DH Jr. Fenestration of the supraclinoid internal carotid artery with rupture of associated aneurysm. *Am J Neuroradiol*. 1984; 5 (5): 634-636.
- 34 Hattori T, Inoue S, Sakai N. Fenestration of the basilar artery associated with persistent primitive trigeminal artery. *Neurol Med Chir (Tokyo)*. 1997; 37 (11): 841-843.
- 35 O'uchi E, O'uchi T. Persistent primitive trigeminal arteries (PTA) and its variant (PTAV): analysis of 103 cases detected in 16,415 cases of MRA over 3 years. *Neuroradiology*. 2010; 52 (12): 1111-1119.
- 36 Mallouhi A, Felber S, Chemelli A, et al. Detection and characterization of intracranial aneurysms with MR angiography: comparison of volume-rendering and maximum-intensity-projection algorithms. *AJR Am J Roentgenol*. 2003; 180 (1): 55-64.
- 37 Metens T, Rio F, Balériaux D, et al. Intracranial aneurysms: detection with gadolinium-enhanced dynamic three-dimensional MR angiography. Initial results. *Radiology*. 2000; 216 (1): 39-46.
- 38 Franklin B, Gasco J, Uribe T, et al. Diagnostic accuracy and inter-rater reliability of 64-multislice 3D-CTA compared to intra-arterial DSA for intracranial aneurysms. *J Clin Neurosci*. 2010; 17 (5): 579-583.

Keiji Sogawa
Radiology
Kameda Medical Center
929 Higashi-cho
Kamogawa City
296-8602 Chiba, Japan
E-mail: bafenestration16416@yahoo.co.jp