Acta Neurochir (Wien) (2006) 148: 139–143
DOI 10.1007/s00701-005-0682-4

*Acta Neurochirurgica*
Printed in Austria

*Clinical Article*

# Characteristics of aneurysms of the internal carotid artery bifurcation

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Received July 7, 2005; accepted September 28, 2005; published online November 30, 2005


## Summary

*Background*. Arterial bifurcations are sites of maximal hemodynamic stress, where cerebral aneurysms commonly develop. However, in our experience with endovascular treatment for aneurysms of the internal carotid artery (ICA) bifurcation, we often experienced that the aneurysmal neck did not necessarily exist only at the ICA bifurcation (ICBi). In this study, we have retrospectively evaluated characteristics of aneurysms at the ICBi.

*Methods*. Ten ICBi aneurysms in 10 consecutive patients were studied retrospectively. The size of the aneurysms, the angles formed between the ICA and the anterior cerebral artery (ACA) and middle cerebral artery (MCA), and the diameter of the ICA, ACA and MCA were measured. Furthermore, to study the relationship between the location of the aneurysmal neck and the bifurcation of the ICA, the distance between the midline of the aneurysmal neck and of the ICA was measured.

*Results*. The average aneurysm size was $6.3 \pm 3.2$ mm and the average neck was $3.1 \pm 1.2$ mm. The average ICA-ACA angle was $57.3 \pm 16.5$ degrees, and the average ICA-MCA angle was $128.9 \pm 24.1$ degrees. The average diameters of the ICA, ACA and MCA were $2.9 \pm 0.5$ mm, $1.9 \pm 0.4$ mm and $2.5 \pm 0.4$ mm, respectively. The average distance between the midline of the aneurysmal neck and the ICA was $1.6 \pm 0.6$ mm, and all aneurysmal necks of the ICBi arose from the side of the ACA.

*Conclusion*. ICBi aneurysms were deviated to the side of the A1 segment of the ACA, where the artery might suffer higher hemodynamic stress.

*Keywords:* Angiography; bifurcation; cerebral aneurysm; internal carotid artery.

## Introduction

Arterial bifurcations are the site of maximum hemodynamic stress in a vascular network [4, 7]. As a result of that hemodynamic forces weaken the apex of an arterial bifurcation, saccular aneurysms have developed at the arterial bifurcations [2, 4, 9]. Turbulent blood flow in the sac of aneurysms and vibration of the wall of aneurysms causes degenerative changes that weaken the wall of aneurysms and allow them to enlarge [2, 8]. On the other hand, during endovascular surgery for aneurysms of the internal carotid artery (ICA) bifurcation, we noticed that the aneurysmal necks did not necessarily form at the ICA bifurcation (ICBi) but were often slightly deviated to the daughter artery. Therefore, we retrospectively analyzed the relationships among ICBi aneurysms, parent arteries, and daughter arteries.

## Methods and patients

Between January 1998 and May 2005, 389 consecutive patients with unruptured or ruptured saccular aneurysms were treated at our institution and affiliated hospital. Among these patients, there were 10 (2.5%) patients with ICBi aneurysms. The patients included 6 women and 4 men ranging in age from 41 to 88 years, with an average age of 63.0 years. Of the 10 ICBi aneurysms, 5 were unruptured and 5 were ruptured; 6 were located on the right side and 4 on the left side. Of the 5 patients with ruptured aneurysms, 1 was Hunt and Hess grade I, 2 were II and 2 were IV; 3 were Fisher grade III, 2 were IV. Two of 10 patients (20%) had additional aneurysms. One patient had an ICA-posterior communicating artery aneurysm, and another had a middle cerebral artery (MCA) aneurysm. Preoperative intra-arterial digital subtraction angiography (DSA) was performed on all patients. In addition, all patients had magnetic resonance angiography (MRA) or computed tomographic angiography (CTA) or both. All 10 ICBi aneurysms were treated surgically by the same neurosurgeon (S.O.). Endovascular surgery with Guglielmi detachable coils was performed in 8 patients. Neck clipping was performed in 2 patients. Nine patients obtained good recovery. One patient was left with severe disability due to the initial subarachnoid hemorrhage and intracerebral hematoma.

The characteristics of the ICBi aneurysms were evaluated by DSA as follows. The size of the aneurysm was defined by measuring the height, width and neck. The angle between the ICA and the A1 segment of the anterior cerebral artery (ACA) on the ipsilateral side was defined as the I-A angle (Fig. 1). The angle between the ICA and the M1 segment of

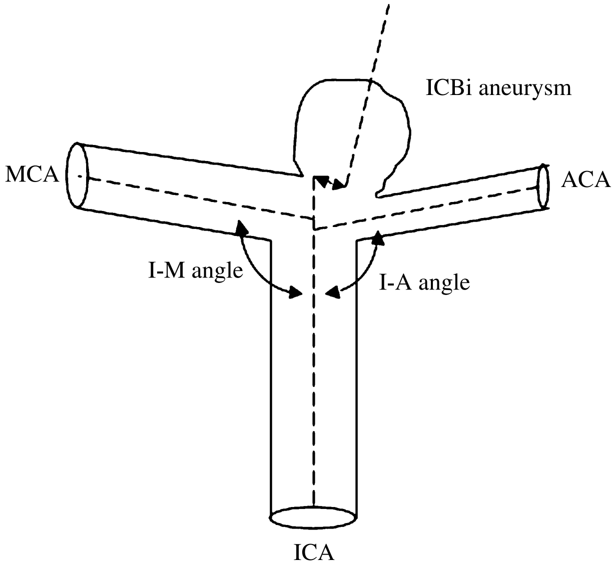


Fig. 1. Schematic drawing of the ICBi with an aneurysm. The angle between the ICA and the ACA was defined as the I-A angle. The angle between the ICA and the MCA was defined as the I-M angle. The distance between the midline of the aneurysmal neck and the midline of the ICA was measured

the MCA on the ipsilateral side was defined as the I-M angle (Fig. 1). I-A and I-M angles were measured using the DSA view that allowed precise verification of the position of the aneurysmal neck; MRA or CTA images were consulted as necessary (Fig. 2). The diameters of the parent and two daughter arteries on the ipsilateral side were measured at the most distal ICA location, and at the most proximal ACA and MCA locations that were not part of the aneurysmal neck.

We classified ICBi aneurysms by type as follows. When the aneurysmal neck was located on a line extending from the midline of the ICA, the aneurysm was defined as an IC-Bi aneurysm (Figs. 3A and 4). Otherwise, the aneurysm was defined as an ICA-ACA or MCA bifurcation (IC-A-Bi or IC-M-Bi) aneurysm according to the daughter artery (ACA or MCA) involved (Figs. 3B, C and 5). To confirm the amount of deviation between the location of the aneurysmal neck and the bifurcation of the ICA, the distance between the midline of the aneurysmal neck and the midline of the ICA was measured (Figs. 1 and 6). The aneurysmal size, vessel diameter, and deviation of the aneurysmal neck from the ICA were measured on DSA films in micrometers and corrected according to the scale on the film.

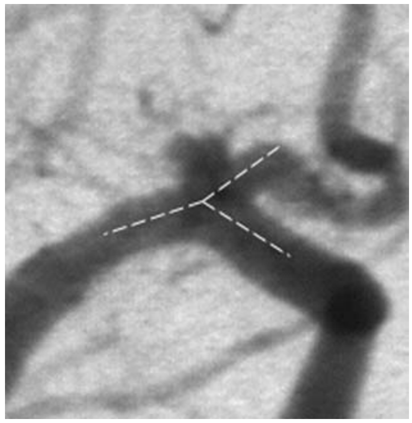

Fig. 2. Case 3: A patient with an unruptured ICBi aneurysm on the right side. The I-A angle was 70 degrees and the I-M angle was 128 degrees

## Results

Table 1 summarizes the results of this study. In 1 of the 10 patients, the A1 segment of the ACA was not found due to an aplastic A1 segment. The average sizes of the aneurysms were: height $6.3 \pm 3.2$ mm (range 2.7 to 12.5 mm); width $5.0 \pm 2.9$ mm (range 2.5 to 10.5 mm); and neck $3.1 \pm 1.2$ mm (range 1.7 to 5.3 mm). The average I-A angles were $57.3 \pm 16.5$ degrees (range 35 to 82 degrees), and the average I-M angles were $128.9 \pm 24.1$ degrees (range 84 to 178 degrees). The average diameters of the ICA, ACA and MCA were $2.9 \pm 0.5$ mm

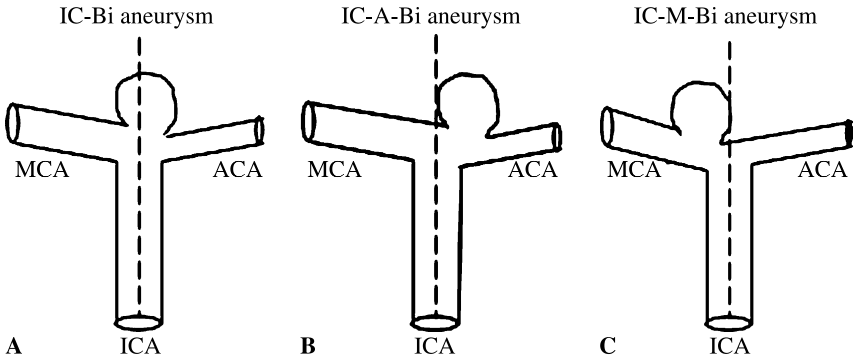


Fig. 3. Schematic drawing of types of ICBi aneurysms classified by position of the aneurysmal neck. (A) When the aneurysmal neck was located on a line extending from the midline of the ICA, the aneurysm was defined as an IC-Bi aneurysm. (B) When the aneurysmal neck was not located on a line extending from the midline of the ICA and the neck deviated to the side of the ACA, the aneurysm was defined as an IC-A-Bi aneurysm. (C) When the aneurysmal neck was not located on a line extending from the midline of the ICA and the neck deviated to the side of the MCA, the aneurysm was defined as an IC-M-Bi aneurysm

Fig. 4. Case 1: A patient with an unruptured ICBi aneurysm on the right side. The aneurysm was classified as an IC-Bi aneurysm because the neck was located on a line extending from the midline of the ICA

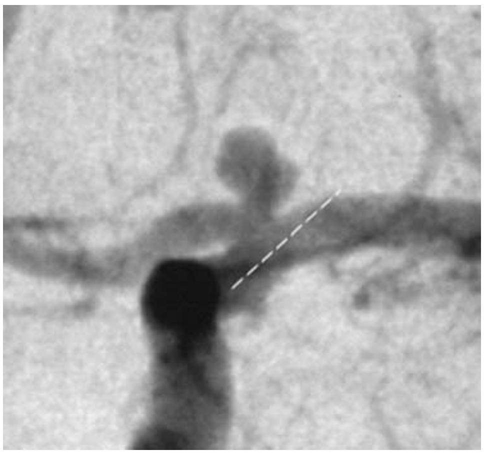

Fig. 5. Case 2: A patient with an unruptured ICBi aneurysm on the left side. The aneurysm was classified as an IC-A-Bi aneurysm because the neck was not located on a line extending from the midline of the ICA and deviated to the side of the ACA

(range 2.1 to 3.5 mm), $1.9 \pm 0.4$ mm (range 1.3 to 2.5 mm) and $2.5 \pm 0.4$ mm (range 2.0 to 3.4 mm), respectively. Three (30%) were IC-Bi aneurysms and 7 (70%) were IC-A-Bi aneurysm. The average distance between the midline of the aneurysmal neck and the midline of the ICA was $1.6 \pm 0.6$ mm (range 1.0 to 3.2 mm), and all aneurysmal necks deviated to the side of the ACA, except in one patient with an aplastic A1 segment of the ACA.

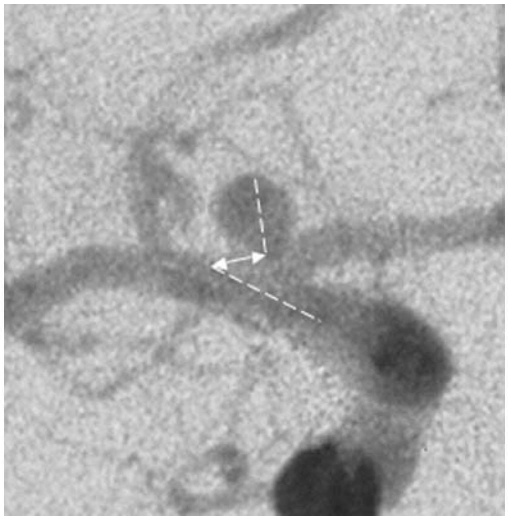

Fig. 6. Case 10: A patient with a ruptured ICBi aneurysm on the right side. The distance between the midline of the aneurysmal neck and the midline of the ICA was 2.0 mm

## Discussion

Hemodynamic forces play a major role in the formation of bifurcation aneurysms at the apex of an arterial bifurcation [4, 9]. Once cerebral arteries are exposed to hemodynamic stress, they may be liable to aneurysm formation because they are poorly supported by surrounding tissue, they have thinner and stiffer walls than extracranial arteries of the same caliber, they lack external elastic lamina, and with increasing age they develop defects of the muscular layer and fenestrations of the internal elastic lamina [7]. The apex of bifurcations is the site of maximum hemodynamic stress in a vascular network because of the impact, deflection, and separation of the blood flow streamlines and because of vortex formation at the lateral angles [4, 7]. The layer with the highest velocity of blood flow moves away from the center of the vessel and toward the apex of the bifurcation when the blood flow is divided at a bifurcation [4]. Furthermore, the larger the bifurcation angle, the more the forces exerted by the daughter arteries will offset one another and the less they will compensate for the force exerted on the apex by the parent artery [4]. Brown [1] has studied the geometry of arterial bifurcations using a mathematical model. He reported that the transmural pressure in the smaller daughter branch is greater than or equal to that in the larger daughter branch and that the larger daughter branch makes a smaller angle with the direction of the parent artery. Ingebrigtsen *et al.* [5] analyzed with respect to vessel radii and bifurcation angles using three-dimensional DSA. They reported that

Table 1. *Summary of 10 patients with aneurysms of the bifurcation of the internal carotid artery*

| Patient | Age/sex | Symptom | Grade of SAH | | Side | Size (mm) | Angle (degree) | | Diameter (mm) | | | Type of aneurysm | Deviation of neck (mm) | Treatment | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | H & H | Fisher | | Height × width × neck | I-A | I-M | ICA | ACA | MCA | | | | |
| 1 | 66/F | unruptured | | | Rt | 7.8 × 5.0 × 4.4 | 82 | 84 | 2.1 | 1.6 | 2.1 | IC-Bi | 1.0 | coiling | GR |
| 2 | 67/F | unruptured | | | Lt | 4.4 × 3.2 × 1.7 | 38 | 143 | 2.9 | 2.3 | 2.7 | IC-A-Bi | 1.4 | coiling | GR |
| 3 | 52/F | unruptured | | | Rt | 2.7 × 2.5 × 2.4 | 70 | 128 | 3.0 | 1.8 | 2.6 | IC-A-Bi | 1.2 | clipping | GR |
| 4 | 78/F | unruptured | | | Rt | 5.4 × 3.5 × 2.1 | 35 | 135 | 2.8 | 2.3 | 2.3 | IC-A-Bi | 1.5 | clipping | GR |
| 5 | 69/M | unruptured | | | Rt | 12.5 × 10.5 × 5.3 | 69 | 115 | 3.0 | 2.1 | 2.8 | IC-A-Bi | 3.2 | coiling | GR |
| 6 | 41/F | ruptured | II | IV | Lt | 10.6 × 9.4 × 4.0 | 65 | 124 | 2.4 | 1.3 | 2.0 | IC-A-Bi | 1.4 | coiling | GR |
| 7 | 52/M | ruptured | II | III | Lt | 4.1 × 3.5 × 3.0 | 53 | 114 | 3.2 | 2.1 | 2.4 | IC-Bi | 1.3 | coiling | GR |
| 8 | 54/M | ruptured | I | III | Rt | 4.0 × 3.5 × 3.0 | 40 | 141 | 2.3 | 1.8 | 2.0 | IC-A-Bi | 2.0 | coiling | GR |
| 9 | 88/M | ruptured | IV | IV | Lt | 7.9 × 5.6 × 4.5 | * | 127 | 3.5 | * | 3.4 | IC-Bi | 0 | coiling | SD |
| 10 | 63/F | ruptured | IV | III | Rt | 4.2 × 3.9 × 2.0 | 64 | 178 | 3.3 | 2.5 | 2.7 | IC-A-Bi | 2.0 | coiling | GR |

* Angle and diameter could not be measured because of aplastic ACA.

the odds ratio for the presence of an aneurysm was 3.46 when comparing the lowest and highest tertile of the observed angle between the parent vessel and the largest branch. The corresponding odds ratio for the smallest branch was 48.06. Fergunson [2] reported that growth of aneurysms occurred as the structural components of the wall were progressively weakened by a process of structural fatigue resulting from the vibration of the wall, produced by the turbulent blood flow in the sac of the aneurysm. Schaller *et al.* [8] mentioned about growth mechanisms of giant aneurysms that the growth might be related to progressive apposition of intramural and/or intraluminal thrombotic material as a result of small hemorrhages within the wall or intraluminal turbulent flow. Geometrical configuration of the aneurysmatic neck and fundus might determine the likehood of thrombosis.

ICBi aneurysms occur at a low incidence, accounting for 3–5% of all intracranial aneurysms, and they are less common even among aneurysms of the ICA [6, 10]. ICBi aneurysms tend to arise at the junction of the ICA and the A1 segment of the ACA rather than at the junction of the ICA and the M1 portion of the MCA [3, 6]. Yasargil [10] reported that ICBi aneurysms tend to have a broad neck, and usually sit on the MCA or ACA, although a specific relationship to the size of the arteries was not recorded. Bifurcation aneurysms, involving ICBi aneurysms, appear not to occur at the bifurcation but deviate to the daughter vessel [3, 6, 10]. However, to the best of our knowledge, there has been no study relating the angles between parent and daughter arteries and the extent of deviation of the neck of ICBi aneurysms.

In the present study, the ICBi aneurysms were located on the side of the ACA in all cases. The features of the parent artery (ICA) and daughter arteries (ACA and MCA) were as follows. First, the I-A angles were much smaller than I-M angles. Second, the diameters of the ACA were smaller than or equal to the MCA in all cases. Our results correspond to results from Brown and Ingebrigtsen [1, 5]. The side of the A1 segment with ICBi aneurysms might suffer higher hemodynamic stress [1, 5]. Although the validity of our results should be evaluated by a sufficient number of cases, ICBi aneurysms deviated to the side of the A1 segment of the ACA. In addition, a greater understanding of this anatomical structure might contribute to more successful endovascular treatment because a microcatheter could be easily inserted into the aneurysmal dome.

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## Comments

The authors describe an interesting study about the characteristics of aneurysms of the internal carotid artery (ICA) bifurcation. They underline the thesis that intracranial aneurysm must be regarded as dynamic lesions with respect to growth, occasionally giving rise to subsequent (subarachnoid) hemorrhage [1]. This is seen by the relatively high rate of unruptured ICA aneurysm in the presented series. In the authors series, the ICBi aneurysms were deviated to the side of the A1 segment of the ACA, where the artery might suffer higher hemodynamic stress. This can be thought to increase the risk of recanalization and even rupture after primary endovascular treatment of this subgroup of aneurysms [2]. To clarify these question, further experimental studies are necessary.

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This article examined the radiological features of 10 internal carotid bifurcation aneurysms in great detail. The finding, to which the authors draw our attention, was that all aneurysmal necks at the carotid bifurcation arose from the side of the anterior cerebral artery. They discussed the haemodynamic stresses on the artery and made the assumption that this stress was higher at the ACA segment, explaining the position of the aneurysms.

Such study may be of some interest to those interested in the possible mechanisms in aneurysm development and thus to some neurosurgeons. However, its impact will be limited by the rarity of these aneurysms, and the increasingly limited number treated by neurosurgeons using open surgery. During surgery one can see the angle of the vessel versus the aneurysm under the microscope and one is armed with the radiological images.

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