Middle Cerebral Artery Aneurysms: An Operative Strategy based on Anatomic–Angiographic–surgical Correlation and using the Pars Triangularis as Intraoperative Landmark

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Objective: The authors present the anatomical and angiographical details that enable surgeons to quickly locate middle cerebral artery (MCA) aneurysms and to gain proximal control without unnecessary delay or premature rupture.

Materials and Methods: The anatomical dissections were performed in 10 adult cadaveric heads from 1993 to 2011 at the Department of Neurological Surgery, University of Florida. The angiographic and the surgical data were derived from 93 MCA aneurysms operated on by Hung Tzu Wen (HTW) from 1996 to 2012 at the Hospital das Clínicas, University of São Paulo and Hospital Samaritano, Brazil.

Results: MCA aneurysms arise most frequently from the M1 segment and less frequently from M2. From a practical viewpoint, the M1 extends from the carotid bifurcation to the MCA genu (on the basal surface of the cerebrum) with specific topographical relationships along the way, and the M2 extends from the MCA genu to the sylvian or “M” point (on the lateral surface), also with specific topographical relationships. The key for the angiographical analysis of an MCA aneurysm is to establish its topographical relationship to the genu of the MCA. If it is proximal to the genu, it is important to estimate its distance to the carotid bifurcation and to the MCA genu. If it is distal to the MCA genu, it is important to estimate its distance to the genu and to the sylvian point (“M” point). Also, it is important to evaluate the direction of the dome of the aneurysm, as it indicates the structures to which the dome is attached. The key for locating an MCA aneurysm intraoperatively is the relationship between the MCA genu and the tip of the pars triangularis. The tip of the pars triangularis is a reliable intraoperative landmark (even when it is obscured by severe subarachnoid hemorrhage) and it is located just distal to the MCA genu and approximately 2 cm distal to the sharp transition between the basal and the lateral surfaces of the cerebrum. Once the pars triangularis is identified, the MCA genu can also be quickly estimated and identified, and thereby so will the aneurysm.

Conclusion: The carotid bifurcation, genu of the MCA, and the “M” point on the AP view carotid angiography, and the sylvian triangle on the lateral projection constitute the cardinal landmarks for locating MCA aneurysms angiographically. Correlating the angiographic location of the aneurysm to the pars triangularis of the inferior frontal gyrus constitutes the key for then locating the MCA aneurysm intraoperatively.

(Received May 11, 2012; accepted May 31, 2012)

Key words: middle cerebral artery aneurysm, microsurgical anatomy, cerebral angiography, microneurosurgery, pars triangularis

Introduction

When dealing with aneurysm surgery, neurosurgeons want to: 1- quickly locate the aneurysm and establish proximal control without wasting time and without causing the aneurysm to rupture prematurely; 2- treat the aneurysm adequately, either by clipping, wrapping, trapping, suturing etc...

It is our firm belief that, in order to achieve those 2 goals, neurosurgeons need to have: a) anatomical knowledge; b) the capability to understand the imaging information, and to correlate it with the anatomy; c) the capability to plan the surgery based on the correlation of anatomy and imaging studies; d) the capability to bring together anatomy, imaging, and presurgical planning into the surgery; and e) fine surgical skill through extensive training. The above mentioned steps “a” to “d” can be summarized as the anatomic-angiographic-surgical correlation.

Objective

In this paper, the first author (HTW) displays his personal experience and lessons learned from the anatomic-angiographic-surgical correlation of 93 MCA aneurysm cases operated on by him in the last 16 years, emphasizing the role of the pars triangularis as an intraoperative landmark in locating those aneurysms. Those lessons have helped HTW to quickly locate the aneurysm and to establish proximal control without unnecessary delay or premature rupture in most of the MCA aneurysm cases.

Materials and methods

The anatomy study of the sylvian fissure and the MCA was performed in 10 formalin-fixed adult cadaveric heads from 1993 to 2011, in the Microneuroanatomy Laboratory of the Department of Neurological Surgery, University of Florida, Gainesville, USA. The clinical cases were based on 93 MCA aneurysm cases operated on by HTW from 1996 to 2012 at the Hospital das Clínicas, University of São Paulo, and Hospital Samaritano, São Paulo, Brazil. In this paper, seven illustrative cases are presented.

Results and discussion

Anatomic considerations

The microsurgical anatomy of the sylvian fissure and the MCA applied to MCA aneurysm surgeries has been previously published. Since most MCA aneurysms involve the M1 and M2 segments, only those 2 segments will be considered here.

The M1 segment of the MCA extends from the carotid bifurcation to the limen insulae, and it is located in the basal component of the sylvian fissure. The M1 segment can be divided into proximal and distal halves. The proximal half is related superiorly to the anterior perforated substance, posteriorly to the upper portion of the anteromedial surface of the uncus, inferiorly to the inferior portion of the anteromedial surface of the uncus, and anteriorly to the stem of the sylvian fissure, the frontotemporal arachnoid reflection, and the lesser wing of the sphenoid. The distal half of the M1 is related superiorly to the anterior portion of the surface of the insula, posteriorly to the inferior portion of the insular pole, inferiorly to the anterior portion of the planum polare, and anteriorly to the stem of the sylvian fissure, frontotemporal arachnoid reflection, and the lesser wing of the sphenoid. (Fig. 1~4)

The M2, or insular, segment is located in the lateral component of the sylvian fissure and it is related to the surfaces of the insula: it begins at the limen insulae, turns around the insular pole to constitute the genu of the MCA, then sends off branches over the anterior and the lateral surfaces of the insula. (Fig. 1~4)

The tip of the pars triangularis of the inferior frontal gyrus is located just distal to the genu of the MCA. (Fig. 5~6)

Anatomic-angiographic considerations

On the anteroposterior (AP) view of the carotid angiography, the neural structures located along the trajectory of the M1 and M2, and the projection of the pars triangularis, just distal to the genu of the MCA can be recognized (Fig. 7). On the lateral view of the carotid angiography, the sylvian triangle and the projections of the anterior, superior and the inferior limiting sulci of the insula can be visualized (Fig. 8).

It is important to evaluate the curvatures of the M1
Fig. 1 Basal view of the right hemisphere to display the topographic relationships of the M1. 1–anterior surface of the insula, 2–genu of the MCA, 3–anterior perforated substance, 4–anterior pole of the insula, 5–supraclinoid internal carotid artery, 6–amygdala.

Fig. 2 Superior view of the right hemisphere to display the topographic relationships of the M1. 1–olfactory tract, 2–genu of the MCA, 3–optic nerve and the lesser wing of the sphenoid, 4–planum polare, 5–anterior pole of the insula, 6–supraclinoid internal carotid artery, 7–anteromedial surface of the uncus (containing the amygdala), 8–temporal horn, 9–sylvian point or “M” point.

Fig. 3 Lateral view of the left insula to display its relationship to the M2 segment of the MCA. 1–corpus callosum. The white arrows indicate the anterior limiting sulcus of the insula; the yellow arrows indicate the superior limiting sulcus of the insula, and the green arrows indicate the inferior limiting sulcus of the insula.

Fig. 4 Frontal view as in angiography. 1–sylvian point or “M” point, 2–uncus and the temporal horn, 3–anterior pole of the insula, 4–optic nerve and the supraclinoid internal carotid artery, 5–genu of the MCA and the lesser wing of the sphenoid.
to establish proximal control: the M1 can be straight, it can curve first upward toward the anterior perforated substance and then curves downward toward the planum polare. When the M1 is straight, it is easy to expose the entire M1, however, when the M1 is curved as described before, it is difficult to expose the segment of the M1 that

Fig. 5 Lateral view of the left hemisphere. The sylvian fissure has been split wide open to display the relationship among the pars triangularis, insular apex and the genu of the MCA.

1-pars opercularis, 2-precentral gyrus, 3-tip of the pars triangularis, 4-pars orbitalis, 5-anterior limiting sulcus of the insula, 6-genu of the MCA, *-insular apex.

Fig. 6 Anatomical dissection as in right pterional exposure (same specimen of Fig. 5). 1-genu of the MCA, 2-middle temporal gyrus, 3-anterior limiting sulcus of the insula, 4-tip of the pars triangularis, 5-pars opercularis, 6-precentral gyrus.

Fig. 7 Anteroposterior (AP) projection of a left carotid angiography. The yellow arrow indicates the genu of the MCA. The red arrow indicates the projection of the pars triangularis of the inferior frontal gyrus. Please refer to Fig. 4 for anatomic-angiographic correlation.

Fig. 8 Lateral projection of a left carotid angiography to display the sylvian triangle. The red arrows indicate the anterior limiting sulcus of the insula; the blue arrows indicate the superior limiting sulcus, and the green arrows indicate the inferior limiting sulcus of the insula. M-“M” point. Please refer to Fig. 3 for anatomic-angiographic correlation.
is hidden toward the anterior perforated substance, it is much easier to just expose the segment that is coursing toward the planum polare, immediately proximal to the aneurysm.

When the angiography of MCA aneurysms is analyzed, it is important to remember that the photograph was taken as if the patient was in erect position; however, in the operating room, the patient is in a supine position, therefore, there is a 90 degree backward change of the position of the patient’s head and the direction of the aneurysm: aneurysms that point anteriorly on angiography will be pointing superiorly in the surgery, aneurysms pointing superiorly on angiography will be pointing posteriorly in the surgery and so on (Fig. 9A, B).

**Anatomic-angiographic–surgical correlation**

The exact location of an MCA aneurysm and its topographical relationship can be determined by the following questions:

- Is this aneurysm located before, at, or after the genu of the MCA?
- If the aneurysm is located before the genu of the MCA, is it in the proximal half, in the distal half, or halfway between the two halves of the M1 segment?
- Is the dome of the aneurysm directed predominantly forward, backward, upward, downward, medially, or laterally?
- What is the predominant course of the M1 segment? Is it straight or curving upward, downward, forward, or backward?

An MCA aneurysm that is located at or distally to its genu is more superficial and usually can be promptly located intraoperatively. As mentioned previously, the pars triangularis covers the apex of the insula that is located just posterior to the pole of the insula. Therefore, when the surgeon splits the sylvian fissure at the level of the pars triangularis, she or he will expose the portion of the MCA that has just turned around the pole of the insula, that is, just distal to the genu of the MCA. If the aneurysm is located soon after the genu of MCA, it will be promptly identified.

If the aneurysm is located before the genu of the MCA, it can be located in the proximal half, in the distal half, or between the halves of the M1 segment. As mentioned previously, the adjacent neural structures are different in those situations.

The predominant direction of the aneurysm dome indicates the surrounding structures to which the aneurysm dome might be attached. Retraction on those structures is to be avoided in the beginning of the dissection of the sylvian fissure.

An MCA aneurysm that points laterally, parallel to the M1 on an AP view in angiography, means that its dome is directed along the sylvian fissure, usually parallel to the course of the M1 segment, and it is pointing toward the surgeon intraoperatively during the pterional approach.

It is very important to know beforehand the course of the M1 segment as demonstrated by Yasargil et al., not only for intraoperative orientation but also for the purpose of proximal control.

The course and the shape of the M1 segment and the height of its origin from the supraclinoid carotid artery can vary considerably. However, the MCA always turns around the pole of the insula to constitute its genu to reach the lateral surface of the insula, regardless the variable course of its M1 segment.

When the M1 segment curves inferiorly on angiography, it will be curving toward the temporal lobe. When the M1 segment curves superiorly on angiography, it will curve toward the anterior perforated substance or toward the anterior surface of the insula. The approximate intraoperative course of the M1 segment can be displayed when we turn the standard AP view angiography upside
down. In some cases, there is no need to expose the entire M1 segment to find the aneurysm or even to find a portion of the M1 segment for proximal control.

The next step is to transport all the information obtained from the angiography to the surgery, and the surgeon’s next questions are the following:

- Toward what direction should I proceed with dissection in the sylvian fissure?
- Where can I or can I not apply retraction to avoid early rupture of the aneurysm?
- Where do I expect to find intraoperatively the aneurysm and the M1 segment for proximal control?

After the appropriate positioning and standard pterional craniotomy, the cerebrum is exposed. First, we have followed routinely the olfactory tract posteriorly to locate the carotid cistern and released CSF from it to relax the brain; this procedure is the same for unruptured or ruptured aneurysms. After having opened the carotid cistern, the carotid artery is identified. Then the sylvian fissure is split, starting at the level of the pars triangularis.
As the pars triangularis is projected over the apex of the insula, as soon as we split the sylvian fissure at that level, we will encounter the M2 segment that has just turned around the insular pole and the apex of the insula.

The anterior pole of the insula and, consequently the limen insulae are located more medially and proximally than the tip of the pars triangularis. The aneurysms that are located soon after the genu of the MCA are located at the level of the pars triangularis, and the aneurysms that are located at the level of the insula pole are projected more medially and proximally in relation to the tip of the pars triangularis. Those aneurysms arising before the insula pole are projected even more medially and proximally in relation to the pars triangularis.

If the aneurysm is located immediately distal to the genu of the MCA, it can be found quickly when the sylvian fissure is split at the level of the pars triangularis. If the aneurysm is located more distally, its location can be estimated by looking at the distance of the aneurysm to the genu of the MCA and to the sylvian point on AP angiography. If the aneurysm is located midway between the sylvian point and the genu of MCA, it probably will be located at the level of the precentral gyrus, or it can be located by looking at the lateral view angiography by locating the aneurysm inside the sylvian triangle. The anterior limit of the sylvian triangle is located at the level of the anterior limiting sulcus that continues superficially as the horizontal ramus of the sylvian fissure, and the sylvian point or “M” point is projected at the anterior margin of the supramarginal gyrus. If it is midway between the two, it probably is located at the level of the precentral gyrus. If it is located at the level of the anterior zone of the insu-

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**Fig. 11**

A: Axial CT scan. There is hydrocephalus and subarachnoid hemorrhage predominantly on the left cerebral hemisphere.

B: AP view of the carotid angiography shows bilateral MCA aneurysms. Both are proximal to the genu of the MCA, on the distal half of the M1s with their domes pointing laterally.

C: Left pterional exposure displaying the cerebrum with intense subpial hemorrhage. The white arrow indicates the approximate location of the tip of the pars triangularis.

D: The sylvian fissure has been split from the tip of the pars triangularis anteriorly to expose the aneurysm.

E: The aneurysm has been clipped.
la, it will be related to the pars opercularis or triangularis. If it is related to the posterior zone of the insula, it will be related to the precentral gyrus or postcentral gyrus. Therefore, the intraoperative location of a distal MCA aneurysm can be calculated between the pars triangularis and the supramarginal gyrus, and the intraoperative identification of the operculum of the precentral gyrus can be a helpful landmark.

However, in most cases of MCA aneurysm, the aneurysm is located at or before the pole of the insula, and its intraoperative location can be easily estimated by looking at the distance between the bifurcation of the internal carotid artery and the genu of the MCA.

In a standard pterional approach, the usual cerebral exposure can be seen in Fig. 10D.

It is possible to see the frontotemporal arachnoid reflection that covers the superficial part of the sylvian fissure. The pars triangularis usually can be determined because it is the only part of the frontal operculum that habitually is “retracted” upward; this in combination with the medial deviation of the planum polare leaves a larger space for the arachnoidal opening. However, when the pars triangularis cannot be promptly identified, an alternative is to check the sharp transition between the orbital and the lateral surfaces of the frontal lobe, as the edge of this transition can be easily seen on the pars orbitalis, which occupies both lateral and basal surfaces of the cerebrum. On the lateral surface, the tip of the pars triangularis is located approximately 2 cm from the sharp transition between the basal and lateral surfaces.

The clinical application of the anatomic–angiographic

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**Fig. 12**  
A: Axial CT scan. There is a slight hydrocephalus and a small frontal infarction.  
B: AP view of the left carotid angiography. The M1 curves first upward then dives downward to originate a large aneurysm that points downward, approximately halfway between the proximal and the distal halves of the M1. After giving rise to the aneurysm, the M1 curves upward and then downward to reach the genu.  
C: Lateral projection of the same carotid angiography shown in 12B. The aneurysm points downward.  
D: A sagittal cut of the angiography–CT confirms that the aneurysm projects downward.  
E: Left pterional exposure. The white arrow indicates the approximate location of the tip of the pars triangularis.  
F: The sylvian fissure has been split. The oculomotor nerve is under the tip of the suction tube; the aneurysm is attached to the planum polare of the temporal lobe.  
G: The aneurysm has been clipped.
correlation can be illustrated in the following cases:

**Illustrative case 1** (Fig. 10A~E): female, 49y, with chronic renal failure, presented an unruptured MCA aneurysm: the M1 is straight, and the aneurysm is located proximal to the MCA genu and just distal to the halfway point between the carotid bifurcation and the MCA genu. The dome is pointing laterally along the sylvian fissure. The objective of this case is to show the normal anatomical features of the sylvian fissure and the exposure of the brain after a standard pterional approach.

**Illustrative case 2** (Fig. 11A~E): female, 66y, day 3 of subarachnoid hemorrhage, Glasgow coma scale (GCS) score 14 at admission. The angiography of this patient is similar to that described in the previous case (just a little bit more distal, but still located at the distal half of the M1, but proximal to the MCA genu).

**Illustrative case 3** (Fig. 12A~G): female, 59y, day 30 of subarachnoid hemorrhage, GCS score 15. The imaging work up showed slight ventriculomegaly and small left frontal infarction. The M1 first curves upward and then downward to create a large aneurysm that is located halfway between the carotid bifurcation and the MCA genu, and its dome projects downward.

**Illustrative case 4** (Fig. 13A~E): female, 40y, day 21 of Fisher grade 1 subarachnoid hemorrhage, GCS score 15. The imaging work up showed a straight M1, and an
aneurysm arising from the distal half of the M1, proximal to the MCA genu, and its dome projects superiorly and medially.

**Illustrative case 5** (Fig. 14A～E) : female, 50y, with chronic renal failure on day 8 of subarachnoid hemorrhage, GCS score 15. The imaging work up showed an M1 that curves first upward and then downward to create an aneurysm that is located at the MCA genu with its dome pointing laterally.

**Illustrative case 6** (Fig. 15A～F) : female, 46y, unruptured aneurysm. The imaging work up revealed an MCA aneurysm distal to the MCA genu; it is located before the halfway point between the “M” point and the MCA genu, just distal to the level of the pars triangularis.

**Illustrative case 7** (Fig. 16A～F) : female, 31y, history of previous subarachnoid hemorrhage on the right hemisphere at age 28 with full recovery. Day 2 of the new subarachnoid hemorrhage, presenting aphasia and right hemiparesis (grade 2). The patient rebled in the morning of the surgery. The imaging work up showed a hematoma in the left sylvian fissure, and a distal MCA aneurysm located slightly distal to the halfway point between the genu and the “M” point, at the level of the transition between the middle third to the posterior third of the sylvian triangle, close to the inferior limiting sulcus of the insula.

The same concept and strategy for locating regular size MCA aneurysms can certainly be extended to large or giant ones; however, those large or giant aneurysms frequently require a much broader variety of therapeutic options which is out of the scope of this paper.

**Conclusion**

The carotid bifurcation, genu of the MCA, the “M” point on the AP view carotid angiography, and the sylvian...
triangle on the lateral projection constitute the cardinal landmarks for locating MCA aneurysms angiographically. Correlating the angiographic location of the aneurysm to the pars triangularis of the inferior frontal gyrus constitutes the key for locating the MCA aneurysm intraoperatively.

Microneurosurgery is all about details. The MCA aneurysm surgery is no exception to the rule: as our knowledge on the anatomy grows, we will be capable to get more information and more details from the imaging studies: consequently, better surgical strategies will be planned, and we will be much more prepared to prevail over our challenges in the surgery to provide better outcomes for our patients.

**Acknowledgment**

We thank Toshio Katsuta M.D. for his partnership and collaboration through the years.
Fig. 16  A : Axial CT scan. There is a hematoma in the left sylvian fissure.
B : Angiography–CT, coronal view. There is a distal MCA aneurysm (arrow); it is located slightly distal to the halfway point between the genu of the MCA and the “M” point.
C : Angiography–CT, lateral view. The arrowhead indicates the aneurysm, and the arrow indicates the “M” point. The aneurysm is located at the level of the transition between the middle third to the posterior third of the insula, close to the inferior limiting sulcus.
D : Intraoperative photograph depicting the surface of the brain after an extended left pterional craniotomy and dural opening. The intense subpial hemorrhage makes the identification of the sulci and gyri difficult. The author’s interpretation of the case was 1–pars triangularis, 2–pars opercularis, 3–precentral gyrus, 4–postcentral gyrus. Tem. : temporal.
E : Intraoperative photograph showing the aneurysm. The arrowheads indicate the distal branches of the M2 branch.
F : Intraoperative photograph. The aneurysm was clipped using only the tip of the clip (because of a lack of clip variety available at the time of the surgery), and the clot in the sylvian fissure was removed. The arrowhead indicates the location of the neck of the aneurysm.

References