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Microsurgical Management of the Middle Cerebral Artery Bifurcation Aneurysms: An Anatomic Feasibility Study

Ali Karadag[a] Baran Bozkurt[b] Kaan Yagmurlu[c] Ada Irmak Ozcan[d] Sean Moen[e] Andrew W. Grande[e]

[a]Department of Neurosurgery, Health Science University, Tepecik Research and Training Hospital, Izmir, Turkey; [b]Department of Neurosurgery, Acibadem University, Istanbul, Turkey; [c]Department of Neurological Surgery, University of Virginia Health System, Charlottesville, VA, USA; [d]Faculty of Medicine, Ankara University, Ankara, Turkey; [e]Department of Neurosurgery, University of Minnesota, Minneapolis, MN, USA

Keywords
Middle cerebral artery · Bifurcation · Anatomy · Aneurysm · Projection

Abstract
Background: The proper head positioning decreases the surgical complications by enabling a better surgical maneuverability. Middle cerebral artery (MCA) bifurcation aneurysms have been classified by Dashti et al. [Surg Neurol. 2007 May;67(5):441–56] as the intertruncal, inferior, lateral, insular, and complex types based on dome projection. Our aim was to identify the optimum head positions and to explain the anatomic variables, which may affect the surgical strategy of MCA bifurcation aneurysms. ***Methods:*** The lateral supraorbital approach bilaterally was performed in the 4 cadaveric heads. All steps of the dissection were recorded using digital camera. ***Results:*** The distal Sylvian fissure (SF) dissection may be preferred for insular type and the proximal SF dissection may be preferred for all other types. Fifteen degrees head rotation was found as the most suitable position for the intertruncal, lateral type and subtype of complex aneurysms related with superior trunk. Thirty degrees head rotation was found the most suitable position for the inferior type, insular type, and subtype of complex aneurysms related with inferior trunk. ***Conclusions:*** The head positioning in middle cerebral bifurcation aneurysms surgery is a critical step. It should be tailored according to the projection and its relationship with the parent vessels of the middle cerebral bifurcation.

Introduction

Middle cerebral artery (MCA) aneurysms account for 20% of all intracranial aneurysms and occur at the level of the bifurcation of the vessel in approximately 80% of cases [1–5]. The anatomical variations of the Sylvian fissure (SF), MCA as well as the dome of the aneurysm make the surgery of interest more challenging. The success rate of the surgery is directly related to the exposure of the an-

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Ali Karadag
Department of Neurosurgery
Tepecik Research and Training Hospital, Health Science University
Güney mahallesi 1140/1 Sokak No. 1 Yenişehir/Konak, Izmir 35020 (Turkey)
egealikaradag@gmail.com

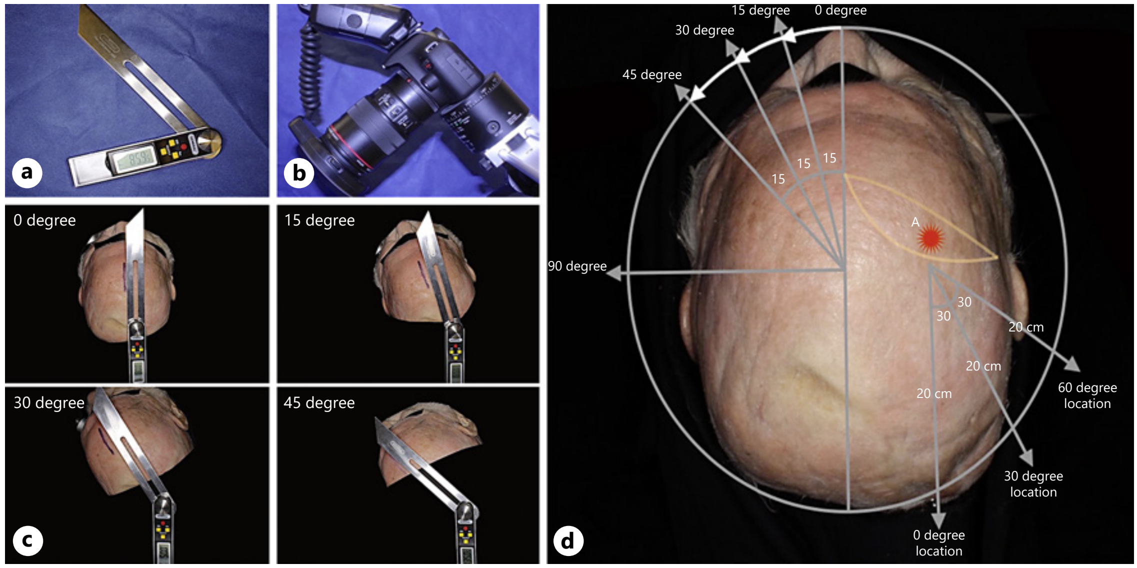

Fig. 1. Electronic protractor (**a**) and the camera with tripod (**b**) are shown in this picture (**a**, **b**). This picture shows the heads in 4 different positions. **c** The head was positioned with 20° extension and we turned it from 0 to 45° at 15° intervals. **d** The head positions and the location of the camera are described. The camera was turned from 0 to 60° at 30° intervals and placed 20 cm behind. A, aneurysm.

eurysm [6]. The surgery of the middle cerebral artery bifurcation aneurysm (MCABA) has been a challenge because of the difficulty of its exposure by dissecting the SF and its close anatomical relationship with parent and perforator vessels. For exposure of the aneurysm, the frontal and temporal opercular retractions are usually necessary after the SF dissection in order to dissect the aneurysm dome and neck away from the around vessels and brain tissue. To make a better surgical strategy decision, some different classification systems have been published according to the dome projection of the MCBAs [2, 7]. We study the most proper head positioning for each type of MCBA classified by Dashti et al. [2] via the lateral supraorbital approach (LSOA).

Material and Method

Four (8 sides) formalin fixed human cadaveric heads were perfused with red and blue colored silicone and were dissected at the University of Minnesota Neuroanatomy Laboratory. The heads were fixed with 3 Mayfield pin holders to secure the position. The dissections were performed under the surgical microscope (Möller 20–1,000) with 6 × 40 high magnification to examine the vascular structures. The fake aneurysms were made from play dough according to the location and direction. Surgical pictures were taken using a Canon EOS Rebel T5 Digital SLR Digital Camera with EF 100 mm f/2.8 L Macro IS USM Lens and a Canon MR-14EX II Macro Ring Lite Flash (Fig. 1a, b). The heads were positioned with a geometric protractor with 20° extension and turned it from 0 to 45° at 15° intervals contralateral to surgical side (Fig. 1c). The camera was placed 20 cm behind and 45° above the level of the head to mimic the view of the surgeon. Anatomic images were obtained from 3 different locations to increase the reliability (Fig. 1d).

Anatomical Classification of MCABA

Yasargil et al. [7] have classified aneurysms into the 3 groups – anterosuperior, towards the SF, posterior and between the M2s. We focused on the classification of Dashti et al. [2] for our cadaver study. They classified the MCBAs into the 5 groups – intertruncal (Fig. 2a), inferior (Fig. 2b), lateral (Fig. 2c), insular (Fig. 2d), and complex (Fig. 2e) [2]. We performed our cadaver study based on the Table 1.

Surgical Technique

The LSOA was performed on cadaveric head in a manner as described elsewhere [8]. The SF was dissected until the MCBA was exposed completely. The arachnoid was opened using sharp dissection until we reached the appropriate area for clipping of MCBA and temporarily clipping of the M1 segment of the MCA. Whereupon, the SF was opened completely for the aneurysm dome visualization and the retractors were placed on the frontal and temporal lobe for taking photographs. The dissections were done according to previously described criterions, considering maximum retraction as the key to success without brain damage.

The appropriate head positioning for MCBA was determined according to the template in Table 1. The correlation between dome projections and the described criterions of 4 head positions (rotation degrees and extension angle) is explained.

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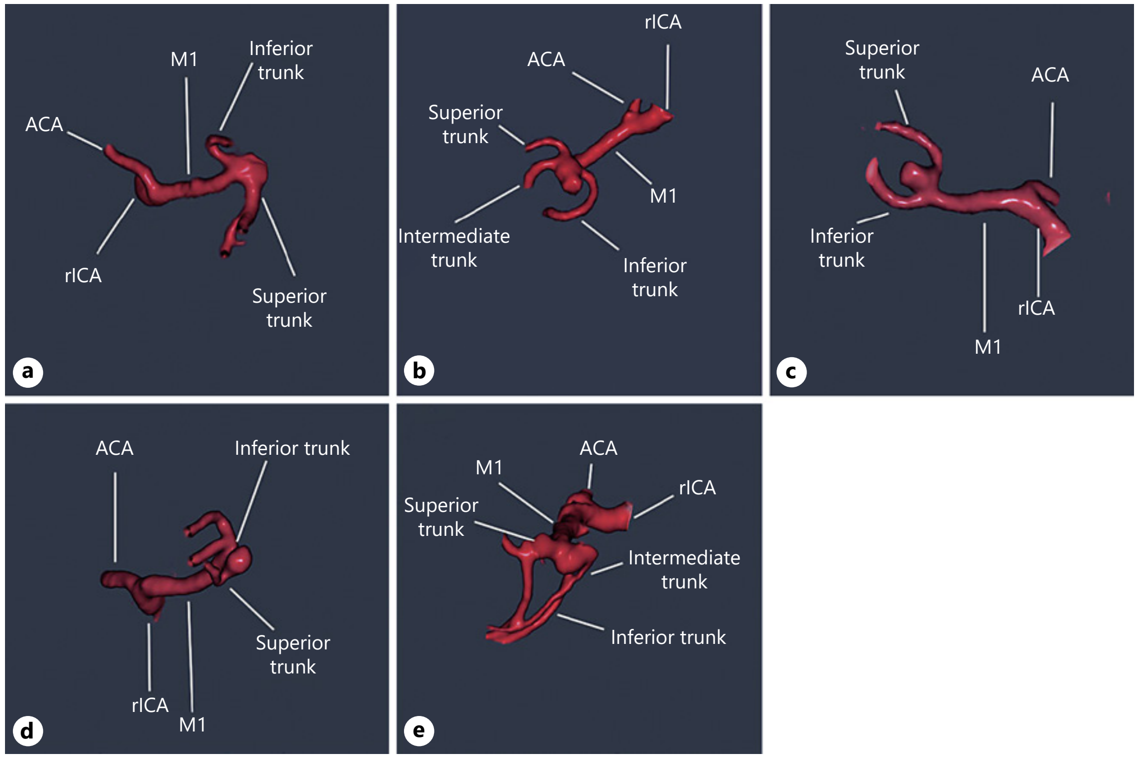

Fig. 2. The pictures which represent the right side vascular structures were obtained by computerized tomography. They show intertruncal type (**a**), inferior type (**b**), lateral type (**c**), insular type (**d**), complex type (**e**). A, aneurysm; ACA, anterior cerebral artery; M1, sphenoidal segment of MCA; rICA, right internal carotid artery; MCA, middle cerebral artery.

Table 1. Description of the MCABAs according their projections and relationship

Type	Position	Direction	Most related structures
Intertruncal	Extending to the ST	Toward the frontal surface	M1 and M2 (superior trunk)
Inferior	Extending the IT	Toward the sphenoid ridge and temporal surface	M1 and M2 (inferior trunk)
Lateral	Between M2s	Same as M1	M1 junction
Insular	Behind the MCA bifurcation	Toward the insular surface	Minimally relation with M2s
Complex	Covering the M1 and M2s	Multidirectional	Both M1 and M2s

MCA, middle cerebral artery; MCABAs, middle cerebral artery bifurcation aneurysms; ST, superior trunk; IT, inferior trunk.

Results

General Considerations

The MCA arises from the internal carotid artery (ICA). It is divided into the 4 segments [9]. These are M1 (sphenoidal) segment, M2 (insular) segment, M3 (opercular) segment, and M4 (cortical) segment [9]. MCA bifurcation, which is a part of the M1, is located in the SF. The M1 continues as M2 (inferior, intermediate, and superior trunk [ST]) [10]. ST and inferior trunk (IT) are the main branches of M2. The ST usually supplies a portion of frontal lobe, and the IT supplies the lateral surface of temporal and parietal lobes. The intermediate trunk (IMT) arises from ST and runs as a small branch [1, 11]. The anatomy of MCA divisions is variable. We can classify them into the 4 types: single trunk, bifurcation, trifurcation, and quadrification [12]. Umansky et al. [13] reported bifurcation in 66%, and trifurcation and quadrification

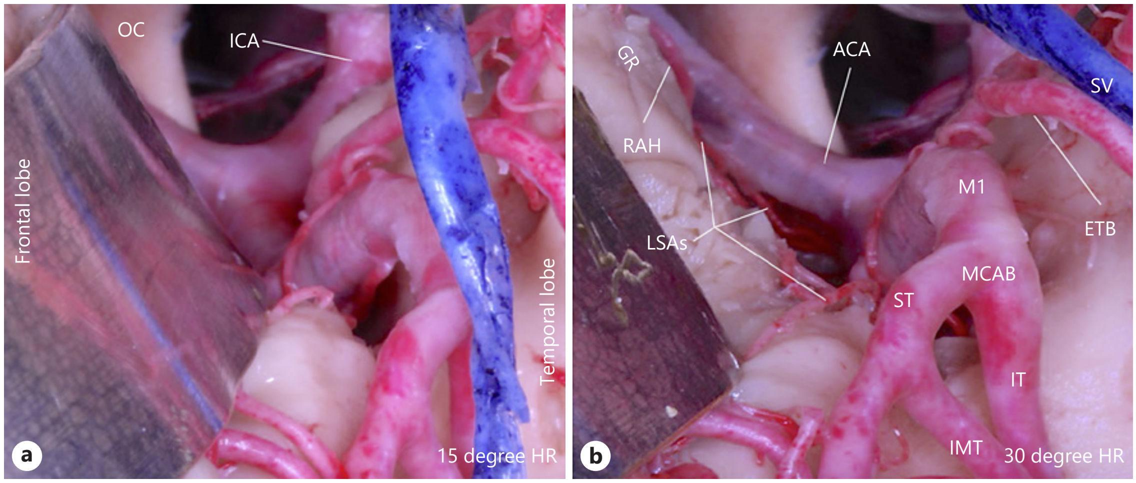

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Fig. 3. This picture was obtained with 15° head position and from 30° location. **a** The carotid and optic cistern were seen clearly and the surgical corridor allows us to use the area around these structures for draining the CSF. This picture was obtained with a head position and location of 30°. The segment of ICA commonly used for temporary clipping was not exposed enough. **b** But we get a better view of the optic nerve and ACA. ACA, anterior cerebral artery; CSF, cerebrospinal fluid; ETB, early temporal branch; GR, gyrus rectus; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; ICA, internal carotid artery; LSAs, lenticulostriate arteries; MCAB, middle cerebral artery bifurcation; OC, optic chiasm; M1, sphenoidal segment of MCA; ST, superior trunk of MCA; SV, Sylvian vein; MCA, middle cerebral artery.

Table 2. Anatomic perspective and currently situations during the dissection stepwise in manner with head rotation

	0° head rotation	15° head rotation	30° head rotation	45° head rotation
Intertruncal type	Ineffective manipulation Unfavorable frontal retraction	Better view for upper part of MCABA Optimum visualization of lenticulostriate arteries	Easier manipulation behind the bifurcation An alternative choice when the brain is swollen	Insufficient temporal lobe retraction Behind the bifurcation was seen clearly
Inferior type	The origin of MCBA cannot be seen clearly	The origin of MCABA cannot be seen clearly Early temporal branch out of the way	Effective final clipping	Needed wider retraction and higher risk of complications
Lateral type	Surgical corridor indiscernible	MCABA remained between ST and IT. Suitable for sharp aneurysmal dissection	Lower quality visualization of ICA	Higher risk for brain damage because of retraction
Insular type	MCABA cannot be exposed as it is behind the bifurcation	Lenticulostriate arteries and peripheral branches are inappreciable Unsuitable for final clipping	Best for visualization and effective manipulation	Bifurcation covers the aneurysm
Complex type	Not suitable with minimal retraction	Better for ST related subtype	Better for IT related subtype	M1 was not seen clearly Craniotomy prevents control on the temporal side

MCABA, middle cerebral artery bifurcation aneurysms; ICA, internal carotid artery; ST, superior trunk; IT, inferior trunk.

in 30%. Gibo et al. [9] reported bifurcation in 78%, and trifurcation and multiple trunks in 22% [9, 13].

The vascularization in SF can be highly complex because of which the dissection may be difficult [2, 14–16]. The MCABAs are explained according to the dome projection with different positions in this study. They are often broad necked and may involve 1 or both inferior, intermediate, and ST (M2s) [2]. The perforators increase surgical complications if they arise from the bifurcation. An important point surgeons need to consider is how to

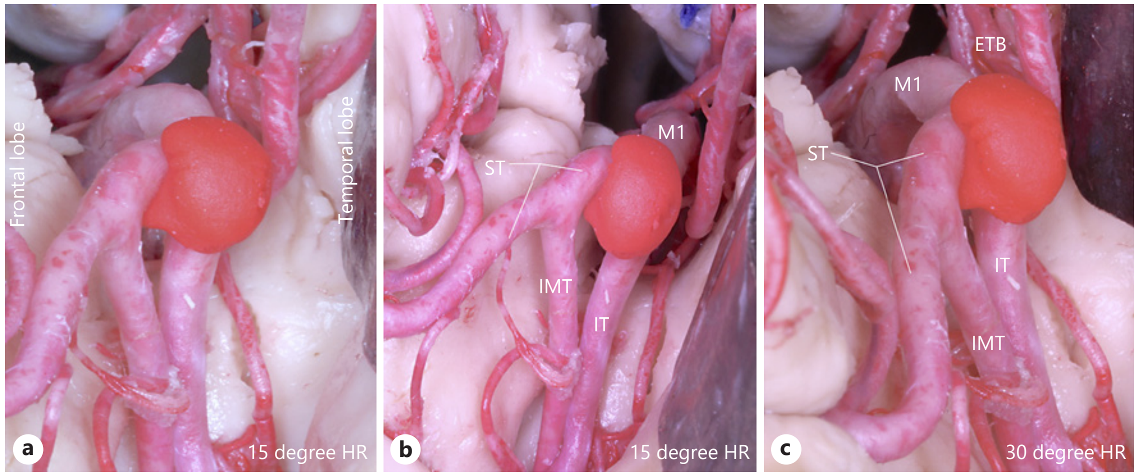

Fig. 4. a The head was positioned at 15° and the photographs were obtained from a 30° location. **b** The head is fixed at a rotation angle of 15° and the camera was placed at 60° location for taking this picture. **c** This picture shows the best view of lenticulostriate arteries and perforators at rotation and location of 30°. A1, The proximal segment of anterior cerebral artery; ETB, early temporal branch; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; MCAB, middle cerebral artery bifurcation; M1, sphenoidal segment of MCA; ST, superior trunk of MCA; MCA, middle cerebral artery.

place the clip or clips without brain damage [14]. The SF dissection was chosen according to the aneurysm positions. The proximal SF dissection is preferred for exposing all the types, except the insular type, which is located behind the MCAB.

The anatomical review was performed based on 5 different aneurysm types using LSOA. A suitable position was determined for taking photographs with 3 different angled head positions. The brain retraction was done till the craniotomy allowed us. The surgical strategy was planned from an anatomical point of view considering the Sylvian dissection, final and temporary clipping, and surgical corridor and aneurysm exposure.

The most appropriate head position for temporary clipping for was similar for all types. The ICA bifurcation can be exposed with 15° head rotation (Fig. 3a). The exposure of the M1 segment of the MCA is provided with 30° head rotation (Fig. 3b). We noted the different head rotations degrees according to the MCABA in Table 2.

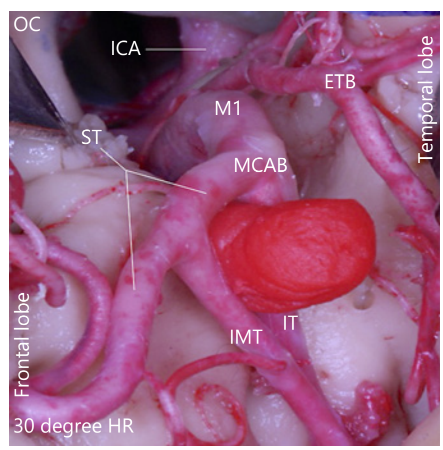

Fig. 5. The aneurysm directed towards the sphenoid ridge is seen. This photograph was obtained from 30° location and rotation; ETB, early temporal branch; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; ICA, internal carotid artery; MCAB, middle cerebral artery bifurcation; M1, sphenoidal segment of MCA; OC, optic chiasm; ST, superior trunk of MCA; MCA, middle cerebral artery.

Intertruncal Type

Intertruncal type aneurysms arise more likely at ST of the MCA. The lenticulostriate arteries arise from between the M1 segment of the MCA and the proximal part of the M2 segment [10]. These arteries should be taken into account in clipping of the intertruncal type. The SF dissection is started close to the temporal lobe as the frontal direction.

A 15° head rotation makes the frontal lobe closer to the dome of the aneurysm and provides a better visualization of the relationship between aneurysm and lenticulostriate arteries. The dome may be exposed clearly, and vascular structures may be easily manipulated. The relationship between aneurysms and M2s is very important for final clipping. Images which are obtained from

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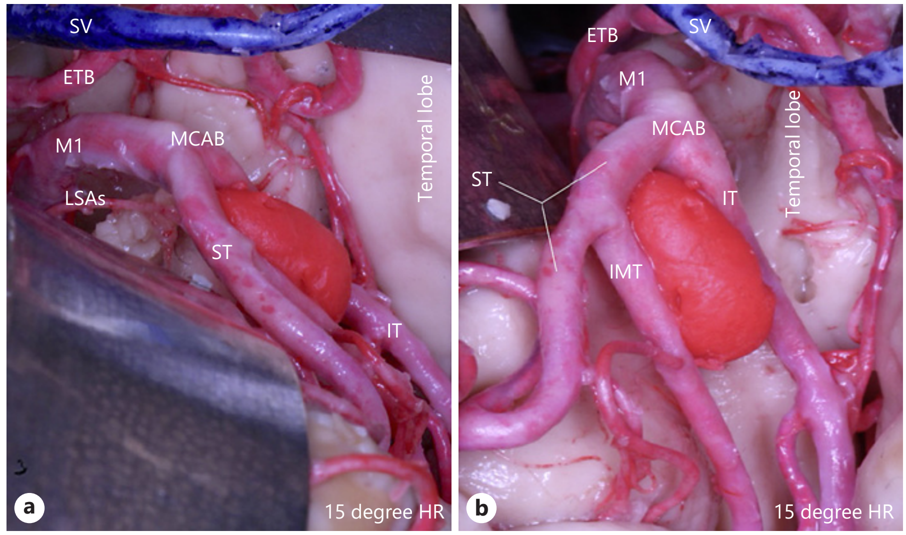

Fig. 6. **a** This photograph was taken from 0° location with 15° head rotation. The head was positioned at 15 head degrees rotation and 30° location. **b** The aneurysm remained between the superior and inferior branch in the surgical corridor. ETB, Early temporal branch; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; LSAs, lenticulostriate arteries; MCAB, middle cerebral artery bifurcation; M1, sphenoidal segment of MCA; ST, superior trunk of MCA; SV, Sylvian vein; MCA, middle cerebral artery.

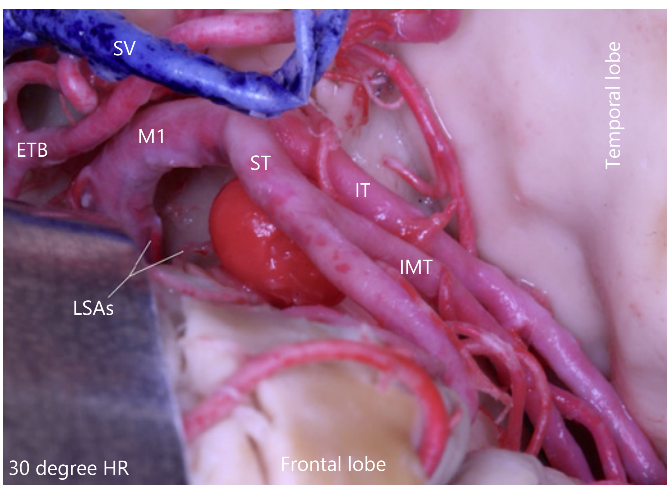

Fig. 7. This picture presented a view which was obtained at head rotation of 30 and 0° location. The relationship between LSAs and the aneurysm neck behind the MCAB is viewed clearly. ETB, early temporal branch; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; LSAs, lenticulostriate arteries; MCAB, middle cerebral artery bifurcation; M1, sphenoidal segment of MCA; ST, superior trunk of MCA; SV, Sylvian vein; MCA, middle cerebral artery.

30° location at 15° head rotation are better. Wider retraction of the temporal lobe provides a suitable view, but this angle is not possible without causing brain damage at 60° location as it is limited by craniotomy. If the brain is swollen and there is a high risk of rupture for intertruncal-type aneurysms in a 30°-head rotation is better than 15° head rotation because it provides a better visualization of the lenticulostriate arteries. Additionally, the final clipping is easier at the 30 and the 60° locations, and the most appropriate head position is 15° (Fig. 4a–c).

Inferior Type

The inferior type aneurysms are commonly related with IT of the MCA. The dome of this type aneurysm is directed toward the sphenoid ridge. The SF dissection is started from the proximal point to the frontal surface to decrease the risk of aneurysm rupture. The early temporal artery passes from the anterosuperior surface of the temporal lobe. The superficial Sylvian veins can cover the aneurysm. The aneurysm may be clipped carefully with 30° location and rotation (Fig. 5). A 60° camera location is not suitable because of the similar direction to the aneurysm dome. This can complicate the surgery and temporal retraction.

Lateral Type

The lateral type aneurysms lie at the same direction as the M1 segment of the MCA aneurysm in the same direction as the M1 segment of the MCA. Hence, the SF is dissected in the proximal to distal direction.

The aneurysm is located between the superior and the ITs of the MCA in the surgical corridor at 15°. Fifteen degrees head positioning is most suitable for dissection and placement of clipping of aneurysm (Fig. 6a, b). A 15° head rotation is ideal for temporary clipping of ICA junction while for a 30° head rotation is ideal for temporary clipping of M1.

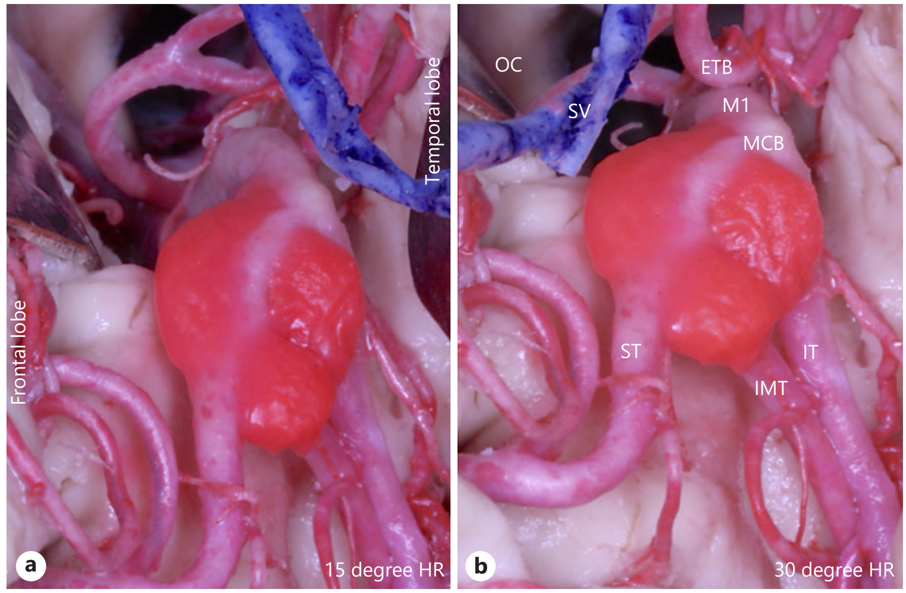

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Fig. 8. The head was fixed at 15° rotation. **a** This is a suitable angle for aneurysms related with ST. This photograph was obtained at 30° head rotation. **b** The relationship between aneurysm and IT is better viewed at this angle. ETB, Early temporal branch; HR, head rotation; IT, inferior trunk of MCA; IMT, intermediate trunk of MCA; LSAs, lenticulostriate arteries; MCAB, middle cerebral artery bifurcation; OC, optic chiasm; M1, sphenoidal segment of MCA; ST, superior trunk of MCA; SV, Sylvian vein; MCA, middle cerebral artery.

Insular Type

The insular type of the MCABA is located behind the MCAB and extends to the insular surface. The distal SF dissection is preferred because minimal retraction is sufficient to expose the aneurysms with a low risk of rupture. At 15° head rotation, the aneurysm is better visualized but not the lenticulostriate arteries and perforators. The best proximal control and the visualization of aneurysm is possible at 0° location at 30° rotation (Fig. 7). Both locations of 30 and the 60° are not suitable because of the M2s overlying the aneurysms. In addition, the control is difficult for lenticulostriate and peripheral branches of the MCA before the final clipping of aneurysm at 30° head rotation.

Complex Type

The complex type of aneurysm has the multidirectional extensions. The anatomical evaluation was done based on 3 type characteristics of complex aneurysms which are wide neck, aneurysm size and position of related arteries. The complex aneurysms may be related to lenticulosriate arteries, perforators and the base of M1, M2 segment of the MCA. The head rotation is preferred based on these indicators. The M1 segment of the MCA or the ICA bifurcation can be used for temporary clipping as explained above, but different clip combinations might be needed. The risk of rupture is very high and the proximal SF dissection is preferred to expose the M1 segment for proximal control before starting the aneurysm dissection.

For aneurysms related with the ST of the MCA, the 15° head rotation to gain a wider temporal and frontal lobes retraction (Fig. 8a). The complex type of aneurysm can also be related to the IT of the MCA. If the head is fixed at 30°, the superior and IMTs remain on the both sides and the aneurysm can be dissected from the perforators (Fig. 8b). In both 15 and 30° head position, the part of aneurysms which is under the bifurcation was seen clearly. The angle of the head rotation can be assessed preoperatively as per the radiological findings.

Discussion

A minor change of head position can greatly affect the surgical strategy [1]. The different techniques of SF dissection and head positions have been described for MCBAs surgery [2, 7]. In our study, we examined the better head positions about the angle of flexion-extension and rotation for the MCABA based on their projections and relationship with parent vessels.

The LSOA was preferred for this study as it is considered a less invasive than the other approaches, has better cosmetic results, requires small craniotomy and low risk of cerebrospinal fluid leak, infection, and other complications [8, 17, 18]. On the other hand, the LSOA has not been preferred for complex giant MCBAs, the exposure of the posteromedial surface of ICA and anterior choroidal artery, and some types of basilar tip aneurysms [8, 18].

One study noted that the head rotation angled from 5 to 10° and the head extension of nearly 15° are needed for MCBAs surgery. Moreover, the head extension should not exceed 20° due to keep the orbital roof away from the surgical corridor. If the head is rotated more than 10°, the cerebrospinal fluid drainage from chiasmatic and carotid cisterns becomes difficult [19]. Among the published studies about classification of aneurysms according to dome projection we used Dashti et al. [2] classification. They have emphasized that the most suitable head rotation is 25–30° towards the contralateral side with minimal extension for intertruncal type, a minimal flexion and 25–30° rotation towards the contralateral side for inferior type, and a minimal flexion with 25–30° rotation towards the contralateral side for lateral type. They also suggested more than 25–30° rotation towards the contralateral side fits well for insular type. They positioned the head based on the visualization of the proximal MCA for complex type [2]. According to Park et al. [4] the head should be positioned 30° toward the contralateral side and if needed, can be extended 20° for routine MCA aneurysms [4].

In our findings, the distal SF dissection may be preferred for insular type of MCABA. For all other types of MCABAs, the proximal SF dissection may be preferred in order to provide the proximal vessel control (ICA bifurcation or M1 segment of the MCA) and temporary clipping, if needed, before exposing the aneurysms. The 15° head rotation was found as the most suitable position for the internal type and lateral type, and a subtype of complex aneurysms related with ST of the MCA. The 30° head rotation was found the most suitable position for the inferior type, insular type, and subtype of complex aneurysms related with IT of the MCA.

Conclusions

The proper head positioning in aneurysm surgery is the one of the most critical in preoperative planning. It should be tailored according to the projection of the MCABAs and its relationship with the parent vessels. It increases the surgical orientation and provides maneuverability that required visualization for perfect clipping in the surgical corridor.

Acknowledgements

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Statement of Ethics

The paper is exempt from Ethical Committee approval. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (name of institute/committee) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Funding Sources

The authors have no funding sources to declare.

Author Contributions

Ali Karadag: Literature search, wrote the main manuscript text, performed the cadaveric dissection. Baran Bozkurt: Revised the manuscript. Kaan Yagmurlu: Collected the data and revised the manuscript. Ada Irmak Ozcan: Revised the anatomical figures and literature search and collected the data. Sean Moen: Revised the radiological data and revised the manuscript. Andrew W. Grande: Edited the manuscript.

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