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SNI: Neurovascular

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Technical Notes

Preoperative simulation of a middle cerebral artery aneurysm clipping using a rotational three-dimensional digital subtraction angiography

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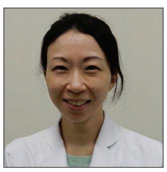

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Received : 22 December 2020
Accepted : 29 January 2021
Published : 23 February 2021

DOI
10.25259/SNI_934_2020

Quick Response Code:

ABSTRACT

Background: In recent years, young neurosurgeons have had few opportunities to gain experience with clipping surgeries. The first author was sometimes surprised that she could not predict the anatomical relationships between the aneurysm and vessels during actual surgery. This study investigated the differences between the expected and actual operative findings during clipping surgery for aneurysms of the middle cerebral artery.

Methods: Medical records for 15 patients who underwent rotational three-dimensional (3D) digital subtraction angiography (3D-DSA) before the clipping surgery were analyzed after the surgery. The anatomical relationships between the aneurysm and parent arteries were defined by the intraoperative findings just before clipping. The viewing direction to obtain this definitive perspective (virtual viewing direction) was measured. The angle between this viewing direction and the coordinate axis was denoted as the "virtual angle for clipping (VAC)."

Results: The VAC between the X-axis and viewing direction on the XY-plane (VAC-XY) ranged from −43° to +73° (mean, +27°), and the angle between the XY-plane and viewing direction (VAC-Z) ranged from +25° to −34° (mean, 5.5°). The difference between the VAC-XY and mean angle was significantly larger in cases with hidden branches behind the aneurysm. In these cases, the virtual viewing direction visualized the neck of the aneurysm. There is no correlation between M1 length and VAC-XY or VAC-Z discrepancy.

Conclusion: 3D-DSA or 3D computed tomography angiography images visualizing the neck of the aneurysm should be obtained in combination with images obtained from the standard oblique angle.

Keywords: Clipping, Intraoperative finding, Middle cerebral artery aneurysm

INTRODUCTION

Clipping surgery for the treatment of cerebral aneurysm has recently become less common because of the development of endovascular intervention. The reduced opportunities for experience with clipping surgery emphasize the need for young neurosurgeons to improve their skills and knowledge during the few opportunities they have to perform this technique. Careful pre- and post-operative examinations and surgery simulation are important for improving the outcome of the surgical procedure.

The first author (Y.K.) has developed a method to obtain a thorough understanding of the anatomical relationships of a middle cerebral artery (MCA) aneurysm as follows: the anteroposterior view is obtained with a three-dimensional (3D) digital subtraction angiography (3D-DSA) or 3D computed tomography angiography (3D-CTA). The image is rotated from the horizontal plane by 30° to the affected side and 10° to the cranial side. This angle was defined as a tentative preoperative standard determined by the fixed head rotation angle.

However, the anatomical relationships between the aneurysm and blood vessels often unexpectedly differed from those in the preoperative simulation. A representative case of an unruptured right MCA aneurysm is shown in [Figure 1]. In this case, a small artery branched from the proximal neck of the aneurysm. The preoperative simulation suggested that the origin of the branch was hidden by the aneurysm [Figures 1a and b]. The initial intraoperative finding was almost the same as predicted. However, moving the microscope and displacing the main trunk visualized the neck of the aneurysm and the clip was successfully applied as shown in [Figure 1c]. Such differences may be common in the experience of expert neurosurgeons, but they surprised Y.K. Further similar experiences lead Y.K. to conclude that the intraoperative findings of an MCA aneurysm are often different from those anticipated based on preoperative imaging.

Therefore, the present study analyzed the differences between the expected and actual operative findings and attempted to determine the optimal 3D-DSA or 3D-CTA viewing angle to correspond with the actual surgical view. The actual view varies from moment to moment during surgery; therefore, the operative findings were defined as the microscope view immediately after the aneurysm was clipped. This study included patients who had undergone 3D-DSA because the viewing angle could easily be measured with this technique.

MATERIALS AND METHODS

This study included 15 consecutive patients who underwent rotational 3D-DSA in preparation for an MCA aneurysm-clipping surgery. Rotational 3D-DSA (Allura Xper FD; Philips, Amsterdam, Netherlands) was performed using the Seldinger technique with a 12-mL (4.0 mL/s) injection of iohexol (Omnipaque 350; GE Healthcare, Princeton, NJ) into the internal carotid artery. The tentative preoperative standard view was orientated at a 30° angle between the anteroposterior axis and the affected side and at a 10° angle between the XY-plane and the cranial side. The surgery was video recorded through the operating microscope. After surgery, the differences between the expected and actual operative findings were analyzed. The origin of the coordinate system was defined as the center of the external acoustic meatus (middle point of the meatal–meatal line). The X-axis was set as a line parallel to the infra-orbitomeatal line, passing through the origin. The Y-axis was set as the meatal–meatal line orthogonal to the X-axis. The Z-axis was set on the line orthogonal to the XY-plane passing through the origin of the XY-plane.

The preoperative 3D-DSA image was then rotated and reconstructed to focus on a very small area that included the aneurysm and its parent arteries. The positional relationships between the aneurysm and parent arteries in this area were obtained by approximating the intraoperative findings just before clipping was performed. The virtual viewing direction of this image was determined.

The angle between the virtual viewing direction and the coordinate axis is denoted as the "virtual angle for clipping (VAC)." The angle between the X-axis and the virtual viewing direction in the XY-plane is denoted as VAC-XY, and the angle between the XY-plane and virtual viewing direction is denoted as VAC-Z. The VAC-XY was expressed as a positive value if the virtual viewing direction originated

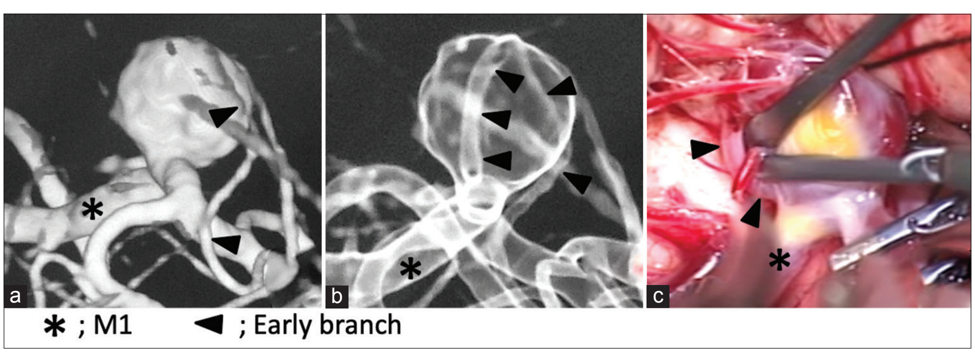

Figure 1: Differences between expected and actual views during clipping surgery for right middle cerebral artery (MCA) aneurysm. (a) Three-dimensional digital subtraction angiography image of the expected view of the aneurysm obtained at 30° from the anteroposterior axis to the affected side and 10° from the XY-plane to the cranial side. The origin of the branch (arrowheads) is hidden by the aneurysm. Asterisk shows the first segment of the MCA (M1). (b) Transparent view with almost the same angle as that in (a). The branch originates from behind the aneurysm. (c) Operative view during application of a clip (arrow). The aneurysm neck is clearly visible.

ipsilateral to the lesion and as a negative value if it originated contralaterally. Similarly, positive VAC-Z was expressed as positive with a cranial viewing angle and as negative with a caudal viewing angle.

[Figure 2] is a simple schema explaining the VAC. We usually expected the "natural view," as shown in [Figure 2a]. After surgical manipulation had displaced the arteries, the operator could visualize the aneurysm [Figure 2b]. This natural view is an approximation of the image shown in [Figure 2c]. We used this angle of the natural view as VAC-XY in all cases. [Figure 2d] shows the 3D concept of VAC.

For example, in the case shown in [Figure 1], the aneurysm and parent arteries appeared as shown in [Figure 1c] at the time of clipping. We reconstructed and rotated the 3D-DSA image to find a position similar to that depicted in [Figure 1c]. In this case, VAC-XY was +2° and VAC-Z was +6°. The VACs and the relationship between the VAC and expected view were analyzed. Then, the relationships between the VAC and aneurysm characteristics, such as aneurysm size, neck size, and presence of hidden branches, were evaluated by Student's *t*-test. We also hypothesized that longer M1's would show a greater difference between the mean VAC and the actual measured VAC.

We measured the M1 length of all 15 cases. The difference between the average VAC and the measured VAC is called VAC discrepancy. We checked if there was a correlation between M1 length and VAC discrepancy using a Pearson test.

Finally, we investigated how to obtain the optimum VAC. This study has been approved by the ethics committee of the institute and informed consent was obtained from patients.

RESULTS

Representative cases

Case 1

A 65-year-old woman was diagnosed with a right MCA aneurysm by follow-up magnetic resonance imaging (MRI) after undergoing clipping surgery for a left internal carotid-posterior communicating artery aneurysm. A small arterial branch was located behind the aneurysm [Figure 3a]. We predicted that the branch origin would be difficult to identify. The initial surgical view was almost the same as the expected view [Figure 3b]. However, the aneurysm neck could be visualized by moving the microscope and shifting the main trunk. The reconstructed image based on the operative findings is shown in [Figure 3c]. Successful clipping was performed. VAC-XY was –22°, and VAC-Z was +8°.

Case 2

A 60-year-old woman had an unruptured left MCA aneurysm that was revealed by MRI during the follow-up examination for a lacunar infarction. The aneurysm was 7 mm in diameter and had a broad neck and a bleb. Based on the tentative preoperative standard view, we expected the M2 inferior branch to hide the M1 and anticipated that the aneurysm neck was located on the side of the superior branch of M2 [Figure 4a]. However, during surgery, the aneurysm neck was easily detected without detaching the bleb in the temporal lobe [Figure 4b]. VAC-XY was +68°, and VAC-Z was +18° [Figure 4c].

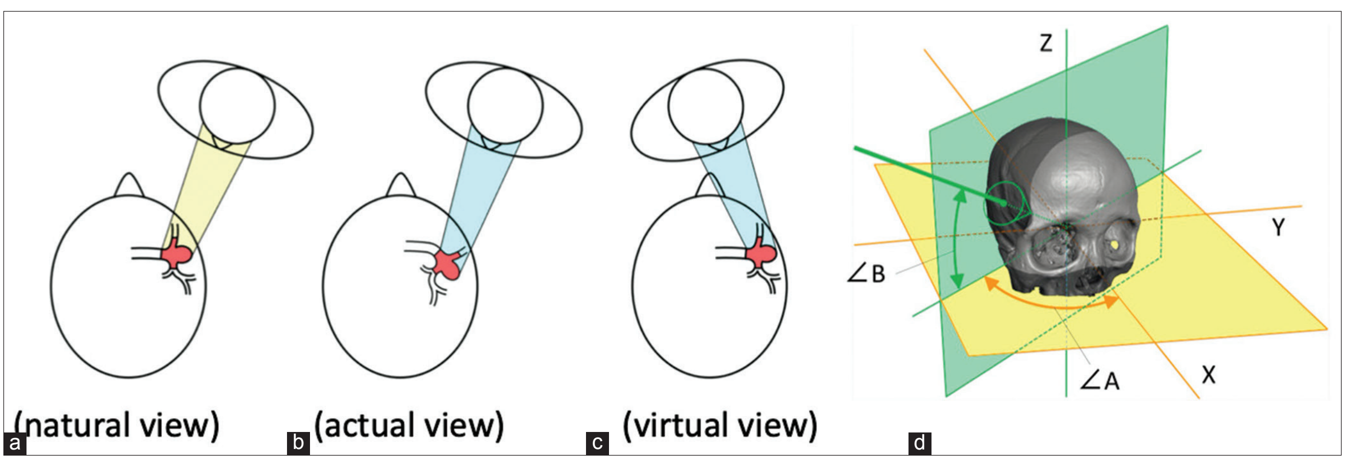

Figure 2: Schema explaining the virtual angle for clipping (VAC). (a-c) Simple schema explaining VAC on the horizontal plane (VAC-XY). We mostly expected the "natural view," as shown in a. Surgical manipulation results in arterial displacement, so the operator can visualize the aneurysm as shown in b. This view is an approximation of the image shown in c. We defined this angle as VAC-XY. (d) Three-dimensional concept of VAC. ∠A=VAC-XY; ∠B=VAC-Z. The X-axis was set as a line parallel to the infra-orbitomeatal line. The Y-axis was set as the meatal–meatal line orthogonal to the X-axis. The Z-axis was set orthogonal to the XY-plane and included the origin for the XY-plane.

Case 3

A 70-year-old woman complained of dizziness. An MRI indicated a left MCA aneurysm with several blebs. A clipping surgery was performed. Based on the tentative preoperative standard view, we expected the M2 inferior branch to be hidden behind the aneurysm [Figure 5a]. [Figure 5b] shows the intraoperative findings. The aneurysm neck was clearly

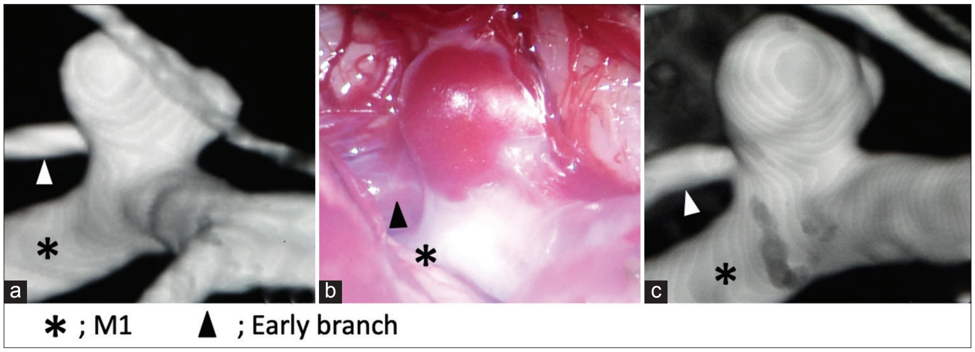

Figure 3: Case 1: Unruptured right middle cerebral artery aneurysm. (a and b) A small arterial branch (arrowhead) emerges from behind the aneurysm (a). We predicted that the branch origin would be difficult to observe. The initial view of the actual surgery was almost identical to the expected view (b), but moving the microscope and shifting the main trunk (M1, asterisk) allowed the operator to visualize the aneurysm neck. (c) Reconstructed image based on the operative view. The origin of the small branch is visible. virtual angle for clipping (VAC)-XY is –22°, and VAC-Z is +8°.

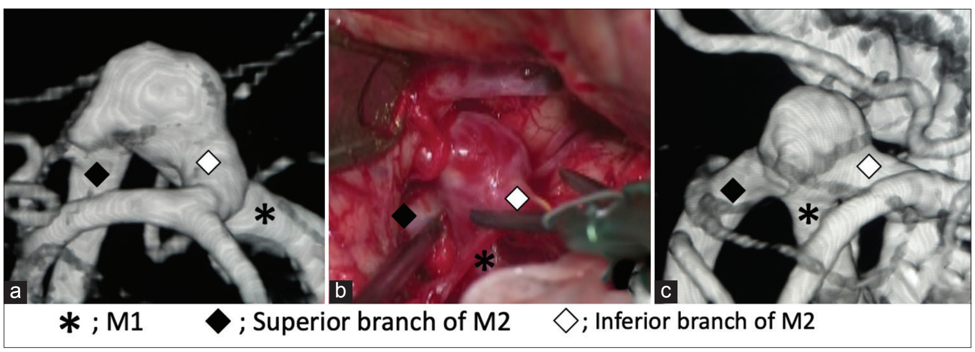

Figure 4: Case 2: Unruptured left middle cerebral artery (MCA) aneurysm with a broad neck and a bleb. Asterisk shows M1; ◇, superior branch of the second segment of the MCA (M2). (a) Expected operative view showing that the inferior branch of the M2 (◆) is hidden behind the aneurysm. (b) During surgery, the aneurysm neck was easily detected without detaching the bleb in the temporal lobe. (c) Reconstructed image based on the operative view. The origin of the inferior branch of the MCA is visible. Virtual angle for clipping (VAC)-XY is +68°, and VAC-Z is +18°.

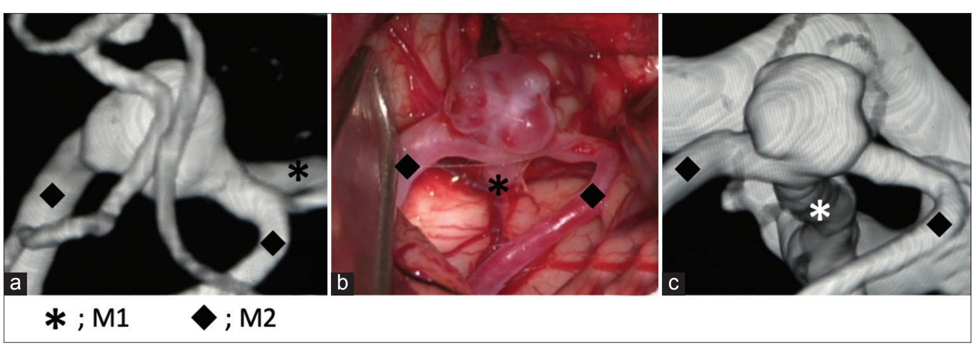

Figure 5: Case 3: Unruptured left middle cerebral artery aneurysm with several blebs. (a) Expected operative view indicates the inferior branch of the M2 (◆) is hidden behind the aneurysm. Asterisk shows M1. (b) Actual intraoperative view easily allows for visualization of the aneurysm neck. (c) Reconstructed image based on the operative view. The origin of the inferior branch of the M2 is visible. Virtual angle for clipping (VAC)-XY was +73°, and VAC-Z was +25°.

visible, and aneurysm clipping was performed successfully. VAC-XY was +73°, and VAC-Z was +25° [Figure 5c].

VAC analysis

VAC-XY ranged from −43° to +73° (mean, +27°) in the 15 cases [Table 1]. VAC-XY was negative (<0°) in two of the 15 cases. The difference between VAC-XY and the mean value was significantly larger in cases with hidden branches behind the aneurysm (P = 0.009), [Figure 6]. VAC-Z ranged from +25° to −34° (mean, −5.5°). Differences between VAC-Z and the mean value showed no relationships with the existence of hidden branches [Figure 7]. There was also no significant difference between the aneurysm size and the presence of the hidden branch. There was no correlation between M1 length and VAC-XY or VAC-Z discrepancy.

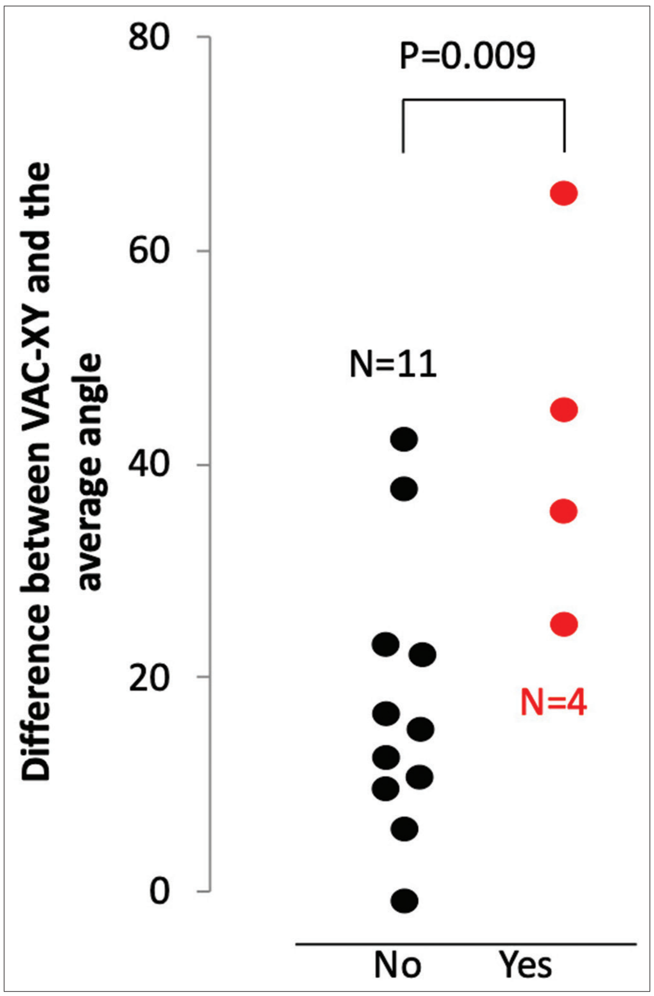

Figure 6: Fifteen aneurysms classified based on the presence (Yes, N=4) or absence (No, n = 11) of hidden branching. Difference between virtual angle for clipping-XY and the mean value was significantly larger in cases with hidden branches behind the aneurysm (P = 0.009).

The correlation coefficient between M1 length and VAC-XY discrepancy was 0.013 with a significance probability of 0.964 and that between M1 length and VAC-Z discrepancy were −0.444 with a significance probability of 0.098.

DISCUSSION

Various head positions have been recommended for clipping surgery for MCA aneurysm, such as "the head is rotated 20–30° toward the opposite side, tilted slightly downwards,"[3,7] or "the head rotation should be limited to 5–10°,"[2] The present first author usually rotates the patient's head by approximately 30°. Therefore, the 3D-DSA reconstruction was orientated with the same angle as that of the expected operative view.

However, the operative findings are often different from the expected operative view because of the movement of the microscope, brain shift, brain retraction, or deformation of the arteries caused by surgical manipulation. Therefore, it is not easy for young surgeons to predict the operative findings actually observed during aneurysm clipping. Several simulators have been developed to predict the operative findings.[1,4,6] However, these approaches have a steep learning curve and the equipment required is expensive. Therefore, we tried developing an easy method for predicting the operative findings that did not require the use of simulators.

Neither the relationships between the aneurysm and its parent arteries nor the aneurysm shape and clip application angle were identical to those predicted from the tentative preoperative standard view in this study. For example, we usually expected VAC-Z to be positive. In fact, VAC-Z was often negative, suggesting that the required perspective was needed from the caudal side. VAC-XY was also negative in two cases, contrary to our expectation. Mean VAC-XY was +27°, which would approximate the expected operative findings. However, VAC-XY ranged from +68° to −43°. VAC-Z ranged from +25° to −34° (mean, −5.5°). The difference between VAC-XY and the mean value was significantly larger in cases

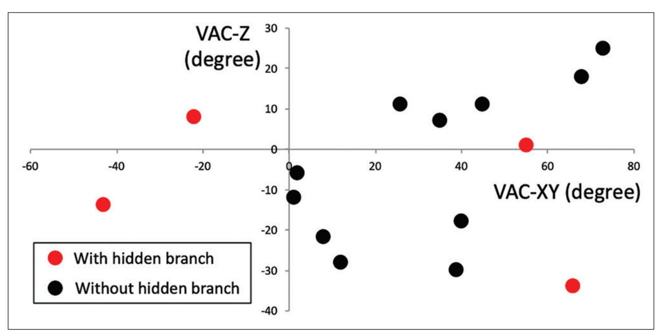

Figure 7: Relationship of virtual angle for clipping (VAC)-XY with VAC-Z in all 15 aneurysms. VAC-Z ranged from +25° to −34° (mean, −5.5°). Aneurysms with hidden branches showed no significant difference between VAC-Z.

Table 1: Characteristics of optimum preoperative view.

Case No.	Side of aneurysm	VAC-XY (degree)	Difference from mean VAC-XY	VAC-Z (degree)	Difference from mean VAC-Z	Branch behind aneurysm	Aneurysm size (mm)
1	R	−22	49	8	−13.53	Yes	4
	L	39	−12	−30	24.47	No	5
3	L	73	−46	25	−30.53	No	6
	R	55	−28	1	−6.53	Yes	6
2	L	68	−41	18	−23.53	No	6
	R	40	−13	−18	12.47	No	7
	L	45	−18	11	−16.53	No	7
	R	26	1	11	−16.53	No	6
	R	−43	70	−14	8.47	Yes	11
	L	8	19	−22	16.47	No	4
	R	12	15	−28	22.47	No	4
	R	2	25	−6	0.47	No	6
	R	35	−8	7	−12.53	No	7
	R	1	26	−12	6.47	No	15
	R	66	−39	−34	28.47	Yes	5

VAC-XY indicates virtual angle for clipping (VAC) between the X-axis and the virtual viewing direction in the XY-plane, VAC-Z, VAC between the XY-plane and virtual viewing direction, R: Right, L: Left

with hidden branches behind the aneurysm, as predicted. This discrepancy has important implications.

Other factors, such as the degree of fixation and orientation of the parent arteries, may affect VAC discrepancy. However, there was no correlation between M1 length and the degree of VAC discrepancy. It is worth noting that differences in the degree of fixation of the parent arteries due to the presence of branch arteries or adhesions, rather than M1 length, might have affected the VAC.

The discrepancy between the VAC and the expected operative view may be due to substantial displacement of the parent arteries by surgical manipulation to visualize the aneurysm neck in the presence of hidden branches. An actual-size model of an aneurysm and parent artery to simulate clipping suggested that the parent artery deviation had the biggest effect on the discrepancy between the estimated and actual operative findings.[5]

During the initial stage of surgery, the operative view was almost the same as the expected view but the operative view changed during the procedure. Finally, just before clipping, the operative view allowed visualization of the aneurysm neck. The angle of this final view corresponded to the working angle for intravascular surgery. Therefore, a preoperative image should be obtained from this “working angle” as well as from the standard oblique angle because the former often resembles the true operative findings, particularly in the case of an aneurysm with a hidden branch.

CONCLUSION

Preoperative 3D-DSA should include an image visualizing the neck of the aneurysm together with an image taken from the standard oblique angle. We conclude that the preoperative views should be prepared as follows: (1) standard oblique angle (30° rotated to the affected side and 10° to the cranial side); (2) specific angle visualizing the neck of the aneurysm; and (3) several views at angles between (1) and (2). These additional views may be important for preoperative simulation.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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How to cite this article: Kimura Y, Mashiko T, Watanabe E, Kawai K. Preoperative simulation of a middle cerebral artery aneurysm clipping using a rotational three-dimensional digital subtraction angiography. Surg Neurol Int 2021;12:70.