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Clinical Article

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Role of Multislice Computerized Tomographic Angiography after Clip Placement in Aneurysm Patients Based on Comparison with Three Dimensional Digital Subtraction Angiography

Objective : We evaluated the accuracy of multislice computerized tomographic angiography (MCTA) in the postoperative evaluation of clipped aneurysms by comparising it with three dimensional digital subtraction angiography (3D-DSA).
Methods : Between May 2004 and September 2006, we included patients with ruptured cerebral aneurysm of the anterior circulation that was surgically clipped and evaluated by both postoperative MCTA and postoperative 3D-DSA. We measured the diagnostic performance and calculated the sensitivity and specificity of postoperative MCTA compared to 3D-DSA in the detection of aneurysm remnants.
Results : A total of 11 neck remnants among the 92 clipped aneurysms (11.9%) were confirmed by 3D-DSA. According to Sindou's classification of aneurysm remnants, 8.7% of clipped aneurysms (8/92) had only neck remnant on 3D-DSA and 3.2% (3/92 aneurysms) had residuum of the neck and sac on 3D-DSA. There were 12 (13.04%) equivocal cases that were difficult to interpret based on the postoperative MCTA. The reasons for the equivocal cases included multiple clips (6 cases, 50.0%), beam-hardening effect (4 cases, 33.3%), motion artifact (1 case, 8.3%), fenestrated clip (1 case, 8.3%) and other combined causes. The sensitivity and specificity of the postoperative MCTA was 81.8% and 88.9%, respectively, by ROC curve (p=0.000).
Conclusion : MCTA is an accurate noninvasive imaging method used for the assessment of clipped aneurysms in the anterior circulation. If the image quality of postoperative MCTA is good quality and the patient has been treated with a single titanium clip, except a fenestrated clip, the absence of an aneurysm remnant can be diagnosed by MCTA alone and the need for postoperative DSA can be reduced in a large percentage of cases.

KEY WORDS : Multislice computerized tomographic angiography · Three dimensional digital subtraction angiography · Aneurysm clipping · Aneurysm remnant.

INTRODUCTION

Postoperative angiography for aneurysm surgery is essential in identifying those aneurysms that have been inadequately clipped, allowing for additional corrective surgery. The current standard of reference for the postoperative evaluation of clipped aneurysms is digital subtraction angiography (DSA). However, DSA is an invasive method requiring arterial puncture and intraarterial catheter manipulation and has a total complication rate of approximately 5% and a permanent stroke rate of approximately 0.5% to 1%[4,9,11]. These complications limit the clinical application of DSA and therefore there is a great demand for a non-invasive screening study to evaluate clipped aneurysms. Recently, multislice computerized tomographic angiography (MCTA) was developed to provide clear vascular images, and it is being widely used in the neurovascular field as MCTA does not carry the risks of DSA and takes less time than DSA. To determine whether postoperative MCTA can replace postoperative DSA, we evaluated the accuracy of MCTA in the postoperative evaluation of clipped aneurysms by comparising it to postoperative three dimensional (3D)-DSA.

MATERIALS AND METHODS

Between May 2004 and September 2006, 201 patients were admitted to our institution with aneurysmal subarachnoid hemorrhage (SAH). We routinely performed surgical clipping

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based mainly on preoperative MCTA except in some special cases and we obtained postoperative MCTA and/or postoperative 3D-DSA. To evaluate the accuracy of the postoperative MCTA results, we compared them to the results of the postoperative 3D-DSA and used the postoperative 3D-DSA as a reference value. We included patients with a ruptured cerebral aneurysm of the anterior circulation that was surgically clipped and evaluated by both postoperative MCTA and postoperative 3D-DSA. We excluded patients who showed a greater than 25% reduction in the diameter of at least one major vessel of the circle of Willis on postoperative MCTA. We performed a detailed review on the medical records of all patients to retrieve information regarding the clinical presentation, location, size and anatomical shape of aneurysm and type and number of clip. We also reviewed the surgical video recordings in which an aneurysm remnant was confirmed by postoperative 3D-DSA.

MCTA was performed using Light Speed Plus CT (General Electronic, Milwaukee, WI) with the following parameter : collimation at 1.25-mm and pitch at 0.75. Before scanning was started, 120 ml Ultravist (Schering AG, Berlin, Germany) was injected via an antecubital vein at 3 ml/s. The scan delay was set by the Smart Prep automatic triggering system (General Electronic). The CT value was measured in the circular regions of interest in the bilateral carotid arteries. When the CT value reached the threshold of 150-250 Hounsfield units (HU) at three consecutive sampling points, helical scanning was automatically started. Axial slices were reconstructed with a 1.25-mm slice thickness at 0.6-mm intervals. Images were processed using Advantage Workstation AW 4.0-04-sol7 (Sun-microsystem). The VR images were produced using a 120-262 HU gradient value and 95% opacity. Both initial and follow-up MCTA were performed in the same manner. DSA was performed with femoral catheterization using the Seldinger technique with a biplane unit (Integris Allura 12&15 Biplane; Philips electronics, Best, Netherlands). Four-vessel angiographies were obtained in anteroposterior, lateral, and bilateral oblique projections for each catheterization. Non-ionic contrast material (Visipaque 320; Amersham Health, Cork, Ireland.) was used in each injection. DSA was performed with a 2 cm field of view (FOV) and a 1024 $\times$ 1024 matrix. The spatial resolution was 2.5 $\times$ 2.5 mm. To obtain three dimensional image, thirty-five milliliters of nonionic contrast material was injected into the internal carotid or vertebral artery with a power injector at 4 ml/s at 500 psi. Twelve milliliters of nonionic contrast material was injected into the internal carotid or vertebral artery with a power injector at 3 ml/s at 600 psi. A 180 rotational DSA was performed within 8 seconds. This information was transferred to a computer (Dell computer, USA) with software (Integris 3D-RA, Philips Intergris Systems) that allows a 3D reconstruction. A volume rendering technique was used for rendering 3D-DSA. We adopted M. Sindou et al.'s classification of aneurysm remnants, and aneurysm remnants were classified in two groups : N-group : with only a neck remnant on 3D-DSA, N-S group : with a residuum of neck + sac[22]. The measurement of the aneurysm remnant on MCTA and 3D-DSA was done using internal digital caliper.

First, we evaluated the usefulness of postoperative MCTA to discriminate between surgical clips and parent vessels according to a 3-point rating scale (i. e, complete separation of parent vessels and surgical clips as "Good", partial separation and/or incorporation of a parent vessel and a surgical clip as "Fair", and intermingling of a surgical clip and a parent vessels with metallic artifact as "Poor"). Second, we evaluated the diagnostic performance of MCTA for the detection of aneurysm remnants using 3D-DSA as a reference value. The presence of aneurysm remnant was assessed on the basis of a 3-point confidence scale, according to which a score of 1 meant definite absence, 2 meant equivocal, and 3 meant definite presence. Finally, the results of postoperative MCTA were compared with those of postoperative 3D-DSA.

We measured the diagnostic performance of postoperative MCTA relative to 3D-DSA for the detection of aneurysm remnants by receiver operating characteristic (ROC) analysis using a 3-point rating scale. The area under the ROC curve, 95% confidence interval (CI), sensitivity, and specificity were calculated. We used the Chi-square test to investigate the influence of the quality of the postoperative MCTA, the number and type of clip, and the location, anatomical shape and size of the aneurysm on the results of the postoperative MCTA. Analysis of the results was performed using the statistical package for the social sciences software (SPSS) (Ver. 11.5; Inc, Chicago,IL). We considered $p < 0.05$ to be significant.

RESULTS

Among 201 aneurysmal SAH patients, 76 patients and 92 aneurysms met the inclusion criteria. The mean age of the patients was 48.74 $\pm$ 10.7 years, and 43 patients were males and the 33 patients were females. Of the 76 patients included in the study, 61 patients had a single aneurysm, and 15 patients had multiple aneurysms. Among the patients with multiple aneurysms, all had 2 aneurysms except for 1 patient with 3 aneurysms. The demographic features of the patients and aneurysm are listed in Table 1. Surgical clipping and postoperative MCTA were performed within a mean interval of 17.9 days, within range of 1 to 238 days. The postoperative MCTA and 3D-DSA were performed within

Table 1. Characteristics of 92 aneurysms and 11 aneurysm remnants

Characteristics	Numbers of clipped Aneurysm (%)	Aneurysm remnant (%)
No. of patients		
Female	33 (43.4)	3 (9.1)
Male	43 (56.6)	8 (18.6)
Total	76	11 (14.4)
Aneurysm location		
Anterior communicating artery	35 (39.1)	8 (22.8)
Middle cerebral artery aneurysm	25 (30.4)	1 (4.0)
Posterior communicating artery	16 (13.0)	2 (12.5)
Anterior cerebral artery	8 (7.6)	0 (0.0)
Internal carotid artery	8 (5.4)	0 (0.0)
Size (mm) of sac on preoperative MCTA		
<7	70 (76.2)	7 (10.0)
7-12	17 (18.4)	2 (11.7)
13-24	5 (5.4)	2 (40.0)
>25	0 (0.0)	0 (0.0)
Size (mm) of neck on preoperative MCTA		
<6	89 (96.7)	10 (11.2)
6-10	3 (3.3)	1 (33.3)
>10	0 (0.0)	0 (0.0)
Shape of aneurysm on preoperative MCTA		
Simple	63 (68.5)	4 (11.2)
Complex	29 (31.5)	7 (33.3)

MCTA : multislice computerized tomographic angiography

a mean interval of 13.4 days, range from 0 to 113 days.

In all patients, pure titanium clips (Sugita titanium aneurysm clip; Mizuho, Tokyo, Japan, Yasagil titanium aneurysm clip; Aesculap AG, Tuttlingen, Germany) with various configurations were used to treat the aneurysms. One or two clips were used for aneurysm surgery in 74 of 76 patients. In two patients with a broad-necked aneurysm (at the bifurcation of a middle cerebral artery and at distal internal carotid artery, respectively), 3 clips were used. A clip of the Fenestrated type was used in 11 of 92 cases, and all other cases used the usual clip. The ability of postoperative MCTA to discriminate between the clip and the parent vessels was graded as good in 58 cases, fair in 33 cases, and poor in 1 case. The cause of poor discrimination was a motion artifact and the causes of fair were focal vasospasm (12 cases, 36.4%), fenestrated clip (10 cases, 30.3%), multiple clips (6 cases, 18.2%), and clip beam-hardening effect (5 cases, 15.1%). The quality of postoperative MCTA was statistically significant for variables in coincidence with postoperative 3D-DSA (p=0.001) by the Chi-square test. Factors including broad base (p=0.017), large aneurysm (p=0.023), and application of multiple clips (p=0.000) and fenestrated clip (p=0.000) had a negative impact on the quality of postoperative MCTA according to the Chi-square test and Two sample T-test. Fenestrated clips were used in 10 of 11 cases with a fair grade on postoperative MCTA. The fenestrated clip was graded as good in only one case upon.

The 3-point confidence scale for postoperative MCTA resulted in "definite absence" in 73 cases, "equivocal" in 12 cases, and "definite presence" in 7 cases. Among the definite absence cases on postoperative MCTA, only one patient showed a remnant aneurysm on postoperative 3D-DSA (false negative). The remnant aneurysm was located in the anterior communicating artery and the quality of the postoperative MCTA was good. The size of the remnant aneurysm was 1.6×1.8 mm on postoperative 3D-DSA (Fig. 1). There were 12 equivocal cases (13.04%) in which it was difficult to interpretate the diagnostic performance of the postoperative MCTA. Among the equivocal cases, 3 patients showed a remnant aneurysm on postoperative 3D-DSA. The reasons for equivocal cases included multiple clip (6 cases, 50.0%), clip beam-hardening effect (4 cases, 33.3%), motion artifact (1 case, 8.3%), and other combined causes (Table 2). The equivocal case due to multiple clip application is shown Fig. 2.

A total of 11 remnant aneurysms among the 92 clipped aneurysms (11.9%) were confirmed by postoperative 3D-DSA. The characteristic features of the remnant aneurysms on postoperative 3D-DSA are listed in Table 3. Of these 11 remnant necks, seven were 2.6-4.6 mm in diameter and four were less than 2 mm. Complete clipping of the aneurysm was achieved in the remaining 81 aneurysms (88.1%). Of factors having an impact on the presence of a remnant aneurysm, broad base multilobulated aneurysm and an anterior communicating artery exerted a statistically significantly unfavorable influence according to the Chi-square test and Two sample T-test. Of 11 aneurysm remnants confirmed on postoperative 3D-DSA, 8 aneurysm remnants were located in the anterior communicating artery and 5 aneurysms had a broad base and multilobulation on preoperative images. In overall, the remnants were found in 33.3% of the large neck group (>6 mm) and 11.2% of the small neck group (<6 mm) (p=0.015) (Table. 1). Patients with aneurysm in the anterior communicating artery had an increased risk of imperfect clip placement (22.2%; 8/36) compared to patients with aneurysms in other locations (5.4%; 3/56) (p=0.015).

According to M. Sindou et al.'s classification of aneurysm remnants, the total group with only a neck remnant (N-

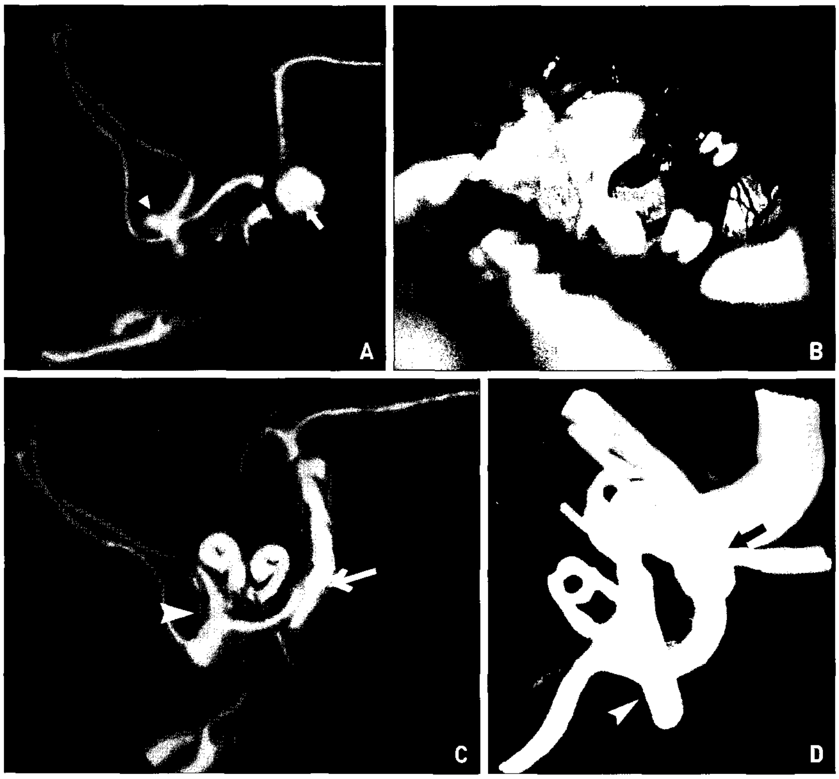

Fig. 1. A 46-year-old man with an aneurysm on the anterior communicating artery and right anterior cerebral artery (right proximal A1.). A : Preoperative multislice computerized tomographic angiography (MCTA) demonstrates a bilobulated aneurysm (arrowhead) on the anterior communicating artery and a large aneurysm (arrow) on the right anterior cerebral artery (proximal A1.). B : On operative field, biloulated and broad base aneurysm (arrowhead) on anterior communicating artery is shown. Temporary clip (arrow) has been applied on right A1. C : Postoperative MCTA performed 11 days after surgical clipping of the anterior communicating artery aneurysm and right anterior cerebral artery aneurysm. At the anterior cerebral artery aneurysm clipping site, the parent vessel are clearly differentiated from the surgical clip (arrow). This case was graded as good for quality of postoperative MCTA. At the anterior communicating artery aneurysm, the definition of the proximal A2 segment is partially incorporated into the clip. This case was graded as fair (arrowhead). Although the quality of the postoperative MCTA was graded as fair on the anterior communicating artery, no remnant is diagnosed based on the postoperative MCTA. D : Postoperative 3D-DSA, the anterior cerebral artery is clipped completely (arrow), but the anterior communicating artery is clipped incompletely (arrow head), different from postoperative MCTA. The size of residual neck was 1.6 × 1.8 mm.

group) on 3D-DSA amounted to 8.7% (8/92 aneurysms) of the whole series, and the group with a residuum of neck + sac (N-S group) on 3D-DSA to 3.2% (3/92 aneurysms). Three patients of N-S group required further intervention. 2 patients among them were successfully treated with reoperation (Fig. 3) and the other was also successfully treated with endovascular technique.

By ROC analysis for postoperative 2D-DSA, the area under ROC curve and 95% CI for postoperative MCTA were 0.884 and 0.742 to 1.025 (p=0.000), respectively. For the postoperative 3D-DSA, the area under ROC curve and 95% CI were 0.864 and 0.703 to 1.024 (p=0.000), respectively. For postoperative MCTA, the area under ROC curve and 95% CI were 0.976 and 0.945 to 1.007 (p=0.001), respectively. The sensitivity and specificity were 81.8% and 88.9% for postoperative MCTA, and 72.7% and 100% for postoperative 2D-DSA, respectively. By the Chi-square test, the coincidence for postoperative MCTA and postoperative 3D-DSA was 93.5%. The Statistically significant variables in coincidence were the number of clips and the quality of the postoperative MCTA (p=0.001). The location of aneurysm, especially anterior communicating artery (88.6%) had a lower significance in coincidence than any other location (96%) but was no statistically non-significant (p=0.436). In addition, the size of the aneurysms was not statistically significant (p=0.438).

DISCUSSION

Although there is still debate as to whether postoperative angiography is useful or even indicated after surgical clipping, it is the only way to confirm that no aneurysm remnant exists. Despite improved microsurgical techniques, many authors[2,8,10,14,16,19,21] have reported that the incidence of residual aneurysms still ranges from 3.5% to 13%. By reviewing the literature published during the period from 1979 through 1999, Thornton, et al.[24] reported an angiographically proven rate of remnant aneurysms after surgical clipping as 5.2% (82 aneurysms among 1569 clipped aneurysms). Rauzzino et al.[19] reported a high incidence of rebleeding in deep midline located aneurysm (especially, anterior communicating artery aneurysm, basilar artery top aneurysm) contrast to the low rate of 3.7% reported by Feuerberg et al.[10]. Also, other authors reported that a partially treated aneurysm may led to regrowth and rebleeding and thus require particular attention[24,25]. Furthermore, because the coiling obliteration of the sac and neck is becoming a more and more popular method, imaging follow-up examinations for surgically treated aneurysms are important not only to evaluate the results of the surgical treatment but also to compare them with the endovascular results. However, the invasiveness of DSA limits its clinical application and therefore there has been great demand for an accurate non-invasive imaging method evaluating clipped aneurysms. When a residual neck remains, long-term postoperative reassessment by a noninvasive technique may be of value especially in young patients. MRA is a noninvasive diagnostic modality but it is not indicated for evaluation of the surgical clipping site, because the image quality of a MRA is severely degraded by the paramagnetic artifact of the clip. Recently, MCTA has been developed to provide clear vascular images, and is widely used in the neurovascular field. Preoperative evaluation of cerebral aneurysms is increasingly being performed using MCTA

Table 2. The Characteristics of the equivocal cases on the postoperative MCTA

No.	Location	Postoper-ative MCTA quality	Size of aneurysm sac on Preoperative MCTA (mm)	Size of aneurysm neck on Preoperative MCTA (mm)	Shape of aneurysm on preoperative MCTA	Result of 3D-DSA	No. of Clip	Type of clip	Cause of equivocal
1	ACOM	Good	6.7×6.5	5.1	Complex	Remnant	2	Straight 9mm Bayonet 9mm	Multiple clip (2)
2	MCA	Fair	14.1×7.4	6.3	Complex	Remnant	3	Ring bent 5mm Ring bent 10mm Rt. angle 7mm	Multiple clip (3)
3	ACOM	Poor	12.1×6.8	5.7	Complex	Remnant	2	Straight 15mm Straight 6mm	Motion artifact
4	ICA	Fair	7.3×5,6	4.2	Simple	No remnant	3	Curved 8.6mm Rt. angle 5mm Reinforce clip	Multiple clip (3) + Skull base*
5	MCA	Fair	4.5×3.5	3.1	Simple	No remnant	2	Bent 6.1mm Curved 3.9mm	Beam hardening effect
6	MCA	Fair	3.6×3.2	2.8	Simple	No remnant	2	Curved 9mm Curved 3.9mm	Multiple clip (2)
7	ACOM	Fair	4.5×3.7	3.2	Simple	No remnant	2	Curved 9mm Curved 7mm	Multiple clip (2)
8	MCA	Fair	2.0×1.6	1.7	Simple	No remnant	2	Bent 5mm Straight 5mm	Beam hardening effect + Multiple clip (2)
9	ICA	Fair	4.9×4.6	3.2	Simple	No remnant	2	Rt. angle 7mm Ring straight 5mm	Beam hardening effect
10	ACOM	Fair	12.2×10.5	6.2	Complex	No remnant	2	Bayonet 10mm Ring straight 5mm	Beam hardening effect
11	PCOM	Fair	6.2×3.7	3.7	Simple	No remnant	1	Bent 7.5mm	Skull base + Focal vasospasm
12	MCA	Fair	7.6×3.7	4.2	Simple	No remnant	2	Bayonet 12mm Ring straight 5mm	Fenestrated clip + focal vasospasm

MCTA : multislice computerized tomographic angiography, 3D-DSA : three dimensional-digital subtraction angiography, ACOM : anterior communicating artery, MCA : middle cerebral artery, ICA : internal carotid artery, PCOM : posterior communicating artery, Skull base* : clip application to close skull base

Fig. 2. A 45-year-old man with a residual neck after clipping of a broad based right middle cerebral bifurcation artery aneurysm. A : Postoperative multislice computerized tomographic angiography (MCTA) was performed 7 days after multiple clipping (arrowhead : right M1, arrow : right M2). The definition of the proximal M2 segment is partially incorporated by the multiple clips. The diagnostic performance of postoperative MCTA was graded as equivocal. B : Postoperative 2D-digital subtraction angiography (2D-DSA) was performed 14 days after surgical clipping. DSA shows a small residual neck of a broad-neck right middle cerebral bifurcation artery aneurysm on oblique view (arrow). C, D : Postoperative 3D-DSA was performed the same day, and unlike postoperative MCTA, it shows a small and definite residual neck (arrow) of a broad base right middle cerebral bifurcation artery aneurysm on before and after subtraction of the clip. (arrowhead : right M1).

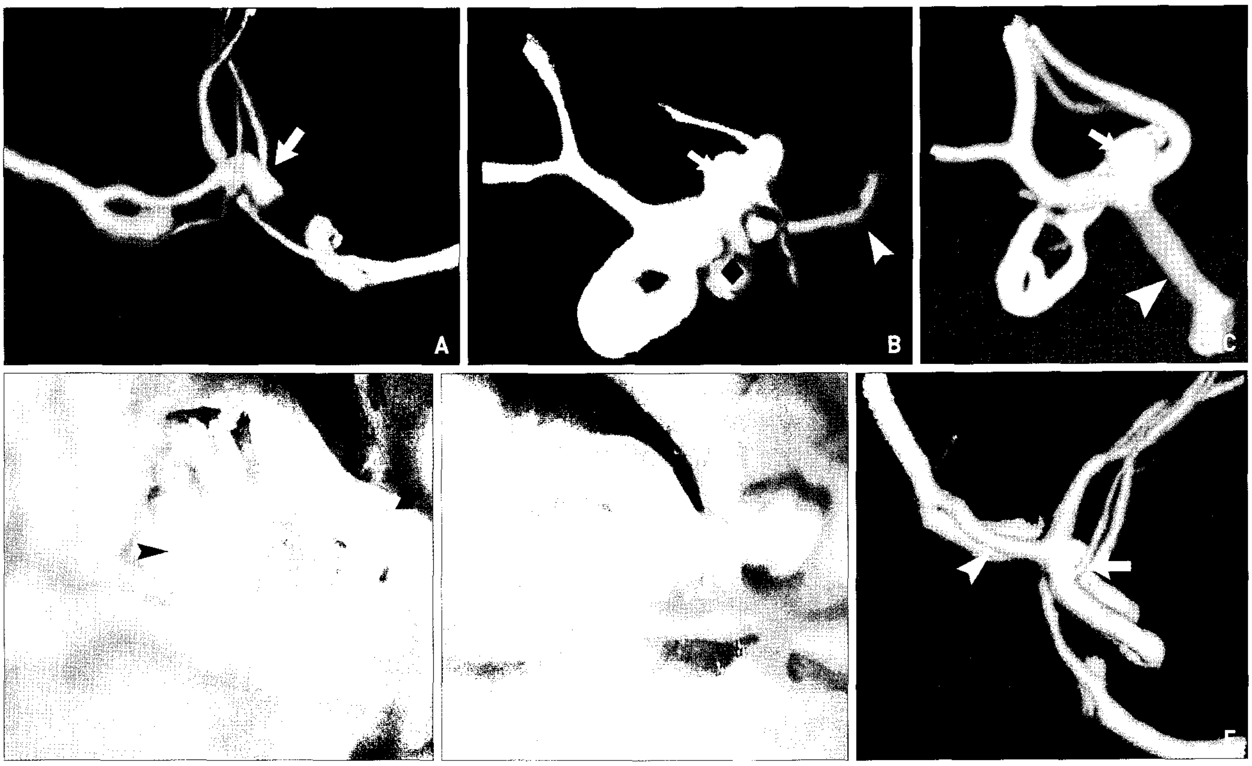

Fig. 3. A 51-year-old man with a residual sac + neck after clipping of a anterior communicating artery aneurysm, which is clearly depicted on postoperative multislice computerized tomographic angiography (MCTA). A : Preoperative MCTA shows a saccular aneurysm (arrow) on the anterior communicating artery. The size of the sac and neck are 8.8×4.1 mm and 4.7 mm, respectively. B : Postoperative MCTA was performed 6 days after surgical clipping of the anterior communicating artery aneurysm. In the left lateral view of the left A1 segment (◆), the residual sac + neck (arrow) is clearly shown at the anterior communicating artery, with a remnant size of 3.4×3.1 mm. (arrowhead : right A2 segment) C : Volume rendering image of postoperative 3D-digital subtraction angiography (3D-DSA) shows a clip and residual sac + neck (arrow) without the artifacts of a clipped aneurysm in the anterior communicating artery and without a size change in the remnant based on postoperative MCTA. (arrowhead : left A1 segment) D : On revision operative field (right pterional approach), the clip from the first operation (left pterional approach) is visible and below the clip, the remnant (arrowhead) is visible. Arrow is right A1 and, White arrow is left A2. E : A complete clipping wis performed with 5 mm right angled clip after removing the clip from the first operation, F : On postoperative MCTA at 15 days after reposition of the clip by 5 mm right angled clip and mini curved 3.9 mm (arrow), no more remnant is present in the anterior communicating artery where remnant had previously been. Arrow head is left A1.

and, as reported recently, we use it routinely for preoperative work-up in patients with aneurysms and in patients suspected of having vasospasm[17,26]. In this study, we hoped to determine the exact accuracy of postoperative MCTA compared with 3D-DSA in the routine postoperative evaluation of patients with aneurysms treated with titanium clips.

Before investigating what percentage of surgically clipped aneurysms have aneurysm remnants upon postoperative MCTA and 3D-DSA, we reviewed the literature to determine the precise definition and types of aneurysm remnants. Interestingly, there are only a few articles providing a precise definition for aneurysm remnants. Rauzzino et al.[19] and Macdonald et al.[15] defined residual filling as filling a portion of the aneurysm greater than 1 mm in size with contrast medium and observing it on at least two angiographic views. David et al.[6] subcategorized the residual aneurysms into two groups which are composed of dog ear and broad-based residuum on postoperative angiography. M. Sindou et al.[22] and V. D'Angelo et al.[5] provided a more precise classification to quantify aneurysm remnants after surgical clipping. We adopted M. Sindou et al.'s classification of aneurysm remnants because it provides us with a precise descriptive scale and allows us to discuss therapeutic decisions. Our postclipping aneurysmal remnant rate was 11/92 (11.9%) on 3D-DSA and 8/92 (8.7%) on 2D-DSA. This is in keeping with the documented literature rates of 3.5%-13% as documented in a recent meta-analysis. Three small aneurysm remnants (case 1, 2, and 4 in Table.2) were not visible on 2D-DSA and detected by 3D-DSA. Surprisingly, two of these were treated with a single titanium clip of simple shape and were detected by postoperative MCTA. The reason why standard DSA failed to detect them was because they were very small remnants on the anterior communicating artery and thus they were sandwiched and hidden between two A2 arteries. According to M. Sindou et al.'s classification of aneurysm remnants, the total cases with only a neck remnant (N-group) on 3D-DSA amounted to 8.7% (8/92 aneurysms) of the whole study group, and 3.2% (3/92 aneurysms) had a

Table 3. Summary of the aneurysm remnants confirmed by postoperative 3D-DSA

No.	Location	Size of aneurysm sac on preoperative MCTA (mm)	Size of aneurysm neck on preoperative MCTA (mm)	Shape of aneurysm on preoperative MCTA	No. of Clip	Type of clip	Result of postoperative MCTA	Result of 2D-DSA	Result of 3D-DSA	Size of remnants aneurysm on postoperative 3D-DSA (mm)	Cause of incomplete clipping	Treatment	Surgical point of view
1	ACOM	4.5×3.8	3.1	Simple	1	Straight 9 mm	Definite presence	Absence	N*	1.4×1.4	Non full visualization	Follow up	Avoidable‡
2	ACOM	6.8×4.2	3.8	Simple	1	Curved 8.3 mm	Definite presence	Absence	N	1.2×1.7	Perforator artery	Follow up	Unavoidable∮
3	ACOM	7.3×4.7	4.9	Complex	2	Side 9 mm Bent 7.5 mm	Definte absence	Presence	N	1.6×1.8	Broad base and multi lobulated aneurysm	Follow up	Unavoidable
4	ACOM	6.7×6.5	5.1	Complex	2	Straight 9 mm Bayonet 9 mm	Equivocal	Absence	N	1.2×1.7	Clip design	Follow up	Avoidable
5	PCOM	4.7×4.6	3.7	Complex	1	Curved 9 mm	Definite presence	Presence	N	2.3×1.8	Non full visualization	Follow up	Avoidable
6	MCA	14.1×7.4	6.3	Complex	3	Ring bent 5 mm Ring bent 10 mm Rt. angle 7 mm	Equivocal	Presence	N	3.3×1.6	Broad base and multi lobulated aneurysm	Follow up	Unavoidable
7	ACOM	3.8×2.4	1.8	Simple	1	Straight 5 mm	Definite presence	Presence	N	2.0×1.4	Non full visualization	Follow up	Avoidable
8	ACOM	5.8×5.1	4.7	Complex	1	Curved 8.3 mm	Definite presence	Presence	N+S†	3.2×3.5	Non full visualization	Coil	Avoidable
9	PCOM	3.0×2.8	2.0	Simple	1	Straight 15 mm	Definite presence	Presence	N	2.2×1.9	Clip design	Follow up	Avoidable
10	ACOM	8.8×4.1	3.7	Complex	1	Curved 8.3 mm	Definite presence	Presence	N+S	3.4×3.1	Non full visualization	Reposition	Avoidable
11	ACOM	12.1×6.8	5.7	Complex	2	Straight 15 mm Straight 6 mm	Equivocal	Presence	N+S	4.3×2.3	Non full visualization	Reposition	Avoidable

3D-DSA : three dimensional-digital subtraction angiography, MCTA : multislice computerized tomographic angiography, 2D-DSA : two dimensional-digital subtraction angiography, ACOM: anterior communicating artery, PCOM: posterior communicating artery, MCA: middle cerebral artery, *N : the group of residual neck only, †N+S : the group of residual sac and neck, ‡Avoidable : defined as avoidable if the anatomical conditions of the aneurysm are favourable to an optimum clipping; in these cases surgical failure is due to other factors, such as the surgeon's expertise and inadequate techniques, ∮Unavoidable : defined as unavoidable if there are unfavourable anatomical conditions, provided that the operation is carried out by an expert team using adequate techniques and with various sets of clips at their disposal residuum of neck + sac (N-S group) on 3D-DSA. The distinction between the N and N-S group appears to have practical importance[22]. As matter of fact, 3 patients of the N-S group required further intervention in our study. 2 patients were successfully treated with reoperation and the other was also successfully treated with endovascular technique[12]. The eight N-group patients had small aneurysm remnants and were managed conservatively. Additional follow-up for these patients will be discussed later. The most common site of remnant aneurysms is the ACoA and this is frequently caused by the presence of a large neck and the fact that the aneurysm is often multilobulated. We also found that ACoA aneurysms with a broad neck and projection to the posterior had a greater chance of having a residual neck than others because of difficult anatomy and incomplete visualization of the aneurysm[5,20,27]. We are impressed that complete visualization of the aneurysm is the main key to preventing an aneurysmal remnant.

One of the advantages of MCTA over single-detector CT is its use of a "thinner beam collimation," by which the metallic artifact caused by surgical clips can theoretically be reduced[3,13,17,26]. In the literature, there are only a few reports on the role of MCTA compared with DSA after clip placement in aneurysm patients[7,13]. Lee et al.[13] reported that the sensitivity and specificity of MCTA were both 100% with respect to aneurysm occlusion (95% confidence interval 29.2-100%). They compared good quality MCTA with DSA. According to our results, postoperative MCTA had a diagnostic accuracy of 81.8% for detection of aneurysm remnants in patients after surgical clipping when compared with 3D-DSA. Our sensitivity and specificity of MCTA were lower than the previous reports because we included the MCTAs regardless of quality for comparison with 3D-DSA to evaluate factors that influence the quality of MCTA and interpretation of the results. 3D-DSA provides more detailed information for evaluating cerebral aneurysms than standard 2D and rotational DSA[23] and 3D-DSA is increasingly being performed before and after embolization[1]. To our knowledge, our report is the only one comparing the results of MCTA with 3D-DSA after clip placement in aneurysm patients. In our study, 2D-DSA missed three small aneurysm remnants on the anterior communication artery that were detected by 3D-DSA.

Among the 11 residual aneurysms confirmed by 3D-DSA, 7 cases had aneurysm remnants detected by MCTA, but the MCTA did not do well in evaluating the other 4 cases (1 false negative, 3 equivocal cases). The multiple clip application and fenestrated type of clips were the main causes of the poor quality in the postoperative MCTA and proved to be an obstacle to interpreting the results because the aneurysm neck could not be evaluated as a result of the overlaying of the clips. Conversely, the size and shape of the aneurysm did not significantly influence the image quality. The beam-hardening artifact also occurred in 4 cases treated with multiple clips. The image degradation caused by the beam-hardening artifact could be minimized considerably by using a higher channel MCTA with thinner beam collimation and advanced techniques[3,13]. Nowadays, we use a 64-channel MCTA in the evaluation of clipped aneurysms which shows a higher resolution image and less beam-hardening artifact. But, we only had a few results using this method so they are not included in this study. Because of the morphologic complexity of the fenestrated type of aneurysm clip, there is an increased dimension, which might result in a more severe artifact than if a single straight type of clip were used. This study confirms the finding that artifacts caused by single titanium clips are limited and rarely interfere with the interpretation of the image. Actually, MCTAs with good quality in our study did not miss small aneurysm remnants less than 2 mm. The disadvantages of postoperative MCTA include the relatively large amount of contrast medium needed to obtain optimal axial source images, the time-consuming effort of excluding the bone structures at the cranial base, and the time required to perform the 3D reconstructions[8,26].

Finally, what should be done with the eight N-group patients in our study? We suspect that in most of these patients the dome was completely occluded (i. e. the clip was completely across the base of the aneurysm), and there was a residual neck between the clip and the arterial lumen. However, if a aneurysm remnant should be found, the imaging follow-up must be planned according to the size of the remnant[12,18]. Clearly, the type of evolution which is most worrying is that of the growth of the remnant, since this is the condition which may lead to rupture. We can clearly see the aneurysm remnants on postoperative MCTA in five cases, so we believe MCTA is sufficient for continued surveillance of aneurysm remnants. The other three aneurysm remnants were not clearly visible on postoperative MCTA due to multiple clip application. To deal with this problem, software will be available in the near future to generate a subtraction image so that the clips can be removed from the images, enabling a better evaluation may be possible. Thus, we think MCTA will be the best noninvasive diagnostic modality not only for the immediate postoperative period but also for the long-term follow-up of patients after clip placement. Although the results of our study are encouraging, further technical improvements and clinical studies are required to replace DSA in the evaluation of clipped aneurysms.

CONCLUSION

MCTA is an accurate noninvasive imaging method used for the evaluation of clipped aneurysms in the anterior circulation. If the image quality of the postoperative MCTA is good and the patient is treated with single standard titanium clip, the absence of an aneurysm remnant can be diagnosed by MCTA alone and the need for postoperative DSA can be reduced in a large percentage of cases.

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