Jpn J Radiol (2013) 31:600–607
DOI 10.1007/s11604-013-0228-2

ORIGINAL ARTICLE

Can sufficient preoperative information of intracranial aneurysms be obtained by using 320-row detector CT angiography alone?

Eri Hayashida · Akira Sasao · Toshinori Hirai · Kiyotoshi Hamasaki · Toru Nishi · Daisuke Utsunomiya · Seitaro Oda · Yasuhiko Iryo · Joji Urata · Yasuyuki Yamashita

Received: 14 March 2013 / Accepted: 28 May 2013 / Published online: 16 June 2013

Abstract

Purpose To determine whether sufficient pre-surgical treatment information of unruptured intracranial aneurysms can be obtained by using 320-row detector CT angiography (CTA) alone.

Materials and methods We enrolled 40 consecutive patients with unruptured intracranial aneurysms. All patients were prospectively conducted to perform 320-detector CTA as the only preoperative modality. Two blinded readers independently assessed CTA images. Interobserver agreement and the agreement between CTA and surgical findings were determined by calculating the κ coefficient. The referring neurosurgeons judged the usefulness of the information provided by CTA for treatment decisions.

Results All patients had surgery without intraarterial digital subtraction angiography. Agreement between CTA and surgical findings was excellent for the aneurysm location ($\kappa = 1.0$) and good for the shape ($\kappa = 0.71$), neck ($\kappa = 0.74$) and its relationship with adjacent branches ($\kappa = 0.71$). Information obtained with 320-detector CTA was highly useful for surgical treatment in 37 of 40 (93 %) patients, although small perforators deriving from the aneurysm in 2 cases were not fully visualized on CTA images.

Conclusion In most patients with unruptured intracranial aneurysms, sufficient pre-surgical treatment information can be obtained by using 320-detector CTA alone.

Keywords Intracranial aneurysm · CT angiography · 320-row CT · Preoperative evaluation

E. Hayashida (✉) · A. Sasao · J. Urata
Department of Radiology, Saiseikai Kumamoto Hospital, 5-3-1 Chikami, Kumamoto 861-4193, Japan
e-mail: eri-hayashida@saiseikaikumamoto.jp

E. Hayashida · T. Hirai · D. Utsunomiya · S. Oda · Y. Iryo · Y. Yamashita
Department of Diagnostic Radiology, Graduate School of Medical Sciences, Kumamoto University, Kumamoto, Japan

K. Hamasaki · T. Nishi
Department of Neurosurgery, Saiseikai Kumamoto Hospital, Kumamoto, Japan

Introduction

Accurate imaging information is needed for safe and proper surgical clipping and endovascular treatment of intracranial aneurysms. Intra-arterial DSA remains the reference standard for the assessment of the aneurysms because of its inherent high spatial and temporal resolution. However, DSA is invasive, time-consuming, demanding of technical skill, and relatively expensive. It also carries a 1–2.3 % risk for neurologic complications that can result in permanent deficits in up to 0.5 % of patients [1].

CTA is a less invasive technique that can be easily performed with a single intravenous bolus injection of contrast medium. It facilitates the rapid evaluation of patients with suspected intracranial aneurysms in the acute or non-acute stage. Multidetector (4-, 16- and 64-row detector) CTA using helical scans can be the primary method for the detection and treatment planning of intracranial aneurysms [2–6], although it has not completely replaced DSA [5–7].

Intracranial aneurysms can now be assessed with 320-row detector CT scanners with a detector width of 16 cm; with these instruments the whole brain can be examined in a single axial scan [8–10]. Although these reports demonstrate the high sensitivity and specificity of

320-row detector CTA in the detection of intracranial aneurysms compared with DSA [8–10], they have not prospectively analyzed the implications of replacing DSA with 320-row detector CTA in a clinical setting. Therefore, it has not been fully understood whether sufficient preoperative information of intracranial aneurysms can be obtained by using 320-detector CTA alone. The purpose of this study was to investigate whether sufficient pre-surgical treatment information of unruptured intracranial aneurysms can be obtained by using 320-detector CTA alone.

Materials and methods

Study population

In a specialized tertiary care center (Saiseikai Kumamoto Hospital), we conducted a prospective nonrandomized clinical study to compare the utility of 320-detector CTA and surgical findings in the detection of and treatment planning for unruptured intracranial aneurysms. Our study was approved by our institutional review board. Informed consent for imaging examinations and surgery was obtained from all patients or their relatives.

Between April 2010 and February 2011, 50 consecutive patients having unruptured intracranial aneurysm underwent 320-detector CTA for pretreatment evaluation. Inclusion criteria were as follows: patients had to be able to undergo both 320-detector CTA and surgical treatment. Ten patients who would undergo coil embolization were excluded. Thus, we enrolled 40 consecutive patients (20 men, 20 women; age range 35–73 years; mean age 57.6 years) with 40 unruptured intracranial aneurysms. All subjects or their relatives were informed of the benefits and risks of surgery for unruptured intracranial aneurysms [11–13].

Of the 40 unruptured aneurysms 15 (37.5 %) were found in patients complaining of headache, dizziness, diplopia, or numbness of the extremities, 14 (35 %) in patients undergoing a brain check-up (brain dock), 4 (10 %) in patients with intracerebral hemorrhage, brain infarcts, or head trauma, 3 each (7.5 %) in patients with subarachnoid hemorrhage (SAH) from ruptured intracranial aneurysms or a family history of SAH, and 1 (2.5 %) was diagnosed in the course of preoperative examination for spinal disease.

CTA

All CTA studies were performed on a 320-row detector CT system (Aquilion One, Toshiba Medical Systems, Nasu, Japan) with a single axial scan. The CTA acquisition protocol consisted of unenhanced and contrast-enhanced studies. An unenhanced CT scan was performed to obtain the mask images for bone subtraction, at a tube voltage of 120 kVp and a tube current of 100 mA. In contrast-enhanced studies the patients were scanned at a tube voltage of 120 kVp and a tube current of 250 mA. The section thickness was 0.5 mm, field of view 240 mm^2, and the scan length 16 cm, covering the entire brain in a 1.5-s single axial scan. The reconstructed voxel size was $0.23 \times 0.23 \times 0.25$ mm. The intravenous (i.v.) injection of iopamidol (Iopamiron 370 mg I/ml; Bayer-Schering, Berlin, Germany) of 300 mg I per kilogram of body weight at a flow rate of 3 ml/s was followed by a 20-ml saline flush delivered with an automated power injector. CT scanning was performed with a semiautomatic contrast bolus-tracking technique (SureStart Protocol; Toshiba Medical Systems) that triggered scanning after an opacification of 200 HU above baseline in the circle of Willis was reached. The mean dose-length product (DLP) for the entire intracranial aneurysm study was 1499.0 ± 696.1 mGy cm; the mean effective dose was 3.1 ± 1.5 mSv.

The images obtained were transferred to and processed on a stand-alone Zio workstation (ZIO station NG1 Version 2.0.1.3; Ziosoft Inc., Tokyo, Japan). To analyze the aneurysms, data were subjected to bone subtraction, multiplanar reconstruction, and 3D visualization using volume rendering. To provide surgical views of arterial and venous structures, data obtained were converted to color-coded 3D reconstructions using the volume-rendering technique [14]. This made it possible to identify arterial and venous structures separately.

Image analysis

Two readers (7 and 23 years of experience in neuroradiology, respectively) independently evaluated the CTA images on a PACS workstation; they were blinded to surgical findings. On CTA images, they assessed overall image quality, the location, shape, and neck of the aneurysm, and the relationship between the aneurysm and arterial branches. Divergent assessments were re-evaluated by the two readers to reach consensus. The consensus reading of the two readers was used for agreement with surgical findings. On the PACS workstation, multiplanar reconstruction- and source images were analyzed in conjunction with corresponding volume-rendering CTA images because of the potential for misinterpretation inherent in the evaluation of the CTA images alone. The software allowed enlargement of regions of special interest in any given spatial orientation.

The overall image quality of the CTA studies was recorded on a 3-point scale where: grade 3, images of sufficient quality for interpretation without apparent artifacts; grade 2, images with mild artifacts that did not interfere with interpretation; and grade 1, images of inadequate quality with severe artifacts that interfered with interpretation.

The aneurysmal origin was recorded as the distal anterior cerebral artery (ACA), the anterior communicating artery (AcomA), the M1–M2 portion of the middle cerebral artery (M1–M2), the M1-anterior temporal artery (M1–ATA), the internal carotid artery–ophthalmic artery (IC–OphA), the internal carotid artery–posterior communicating artery (IC–PC), the internal carotid–anterior choroidal artery (IC–AChA), the top of the basilar artery (BA-top), the basilar artery-superior cerebellar artery (BA–SCA), the vertebral artery–posterior inferior cerebellar artery (VA–PICA), and other locations. The recorded aneurysmal shape was based on its contour and included the number of lobes: grade 1, no lobes; grade 2, one or two lobes; grade 3, more than 2 lobes. The relative size of the aneurysm neck to the dome was recorded as narrow (smaller than the diameter of the aneurysm dome), medium (equal to the dome diameter), and wide (larger than the dome diameter). When an aneurysm at the M1–M2 portion of the middle cerebral artery involved the M2 branch, it was defined as a wide-necked aneurysm. The relationship between the aneurysm and adjacent arteries was classified as grade 1 (no arterial branches from the aneurysm), grade 2 (arterial branches from the aneurysm neck), and grade 3 (arterial branches from the aneurysm dome).

Assessment of surgical findings

To understand all aspects of the aneurysms, neurosurgeons used intraoperative endoscopic examinations (Olympus Co., Tokyo, Japan) during surgery. Two experienced neurosurgeons who performed or assisted at the operations consensually recorded their surgical findings by digital video during the procedures. With the grading system used at CTA assessment they evaluated the location, shape, and neck of the aneurysm, and the relationship between the aneurysm and arterial branches.

The referring neurosurgeons retrospectively and consensually reported the usefulness for treatment decisions of the information provided by CTA, where: grade 3, sufficient information about the aneurysm and venous structures and highly useful for treatment decisions; grade 2, useful but not enough information on the aneurysm and venous structures for treatment decisions; and grade 1, insufficient information on the aneurysm and venous structures for treatment decisions requiring additional DSA data.

Statistical analysis

In results from the 2 readers and the CTA and surgery, the percentage of number in exact agreement relative to the total number was assessed. Interobserver agreement between the 2 readers of the CTA images and agreement between consensus readings of CTA and surgical findings were determined by calculating the κ coefficient ($\kappa < 0.20$, poor; $\kappa = 0.21$–0.40, fair; $\kappa = 0.41$–0.60, moderate; $\kappa = 0.61$–0.80, good; $\kappa = 0.81$–0.90, very good; and $\kappa > 0.90$, excellent agreement). A statistical package (MedCalc Software, Mariakerke, Belgium) was used for all analyses.

Results

Intraoperatively, 14 of the aneurysms were found at M1–M2, 8 each at AcomA or IC–PC, 5 at IC–AchA, and one each at the distal ACA, M1–ATA, IC–OphA, VA–PICA, and at a duplicated middle cerebral artery. The maximum aneurysm diameter ranged from 2 to 10 mm (mean 4.5 mm). In all cases, the 2 readers judged the overall quality of CTA images as grade 3. Interobserver agreement was excellent ($\kappa = 1.0$).

Table 1 Summary of CTA and surgical findings for aneurysm location

	CTA		Interobserver exact agreement	CTA[a]	Surgery	Exact agreement between CTA and surgical findings
	Reader 1	Reader 2				
AcomA	8	8		8	8	
Distal ACA	1	1		1	1	
M1–M2	14	14		14	14	
M1–ATA	1	1		1	1	
IC–PC	8	8	40/40	8	8	40/40
IC–AChA	5	5	(100 %)	5	5	(100 %)
IC–OphA	1	1		1	1	
VA–PICA	1	1		1	1	
BA–SCA	0	0		0	0	
BA-top	0	0		0	0	
Others[b]	1	1		1	1	

[a] Consensus reading of the two readers

[b] Others include duplicated MCA

The summary of CTA and surgical findings for aneurysm location in 40 aneurysms is shown in Table 1. In all studies the consensual interpretation of CTA and surgical findings coincided with respect to the aneurysm location (Table 1; Fig. 1). Interobserver agreement between both readers of the CTA images and agreement between the consensus readings of CTA and surgical findings were excellent ($\kappa = 1.0$; 95 % CI 1.00–1.00).

Table 2 shows the summary of CTA and surgical findings for the aneurysm shape, neck and the relationship between the aneurysm and adjacent arteries in 40 cases with unruptured aneurysm. Surgical findings identified the aneurysm shape as grade 2 in 17, as grade 1 in 15, and as grade 3 in 8 aneurysms (Figs. 1, 2). In their analysis of the aneurysm shape the 2 readers reviewing CTA images agreed in 35 of 40 studies (88 %); interobserver agreement was recorded as very good ($\kappa = 0.82$; 95 % CI 0.67–0.97) (Tables 2, 3). Agreement between the consensus readings of CTA and surgical findings was good ($\kappa = 0.71$; 95 % CI 0.53–0.89).

The neck was intraoperatively recorded as medium in 26, as narrow in 8, and as wide in 6 aneurysms (Figs. 1, 2). Independently, the readers reviewing CTA images agreed on the neck size in 32 of the 40 aneurysms (80 %); interobserver agreement was recorded as good ($\kappa = 0.80$; 95 % CI 0.66–0.96) (Tables 2, 3). CTA and surgical findings were in agreement in 30 of the 40 aneurysms (75 %) (Figs. 1, 2). Agreement between consensus readings of CTA and surgical findings was good ($\kappa = 0.74$; 95 % CI 0.54–0.94).

Intraoperatively, the relationship between the aneurysm and adjacent arteries was recorded as grade 2 in 20, as grade 1 in 17, and as grade 3 in 3 aneurysms (Figs. 1, 2, 3). In their analysis of the relationship between the aneurysm and adjacent arteries, both readers reviewing CTA images agreed in 36 of 40 studies (90 %); interobserver agreement was very good ($\kappa = 0.83$; 95 % CI 0.49–1.00) (Tables 2, 3). Agreement between consensus readings of CTA and surgical findings was good ($\kappa = 0.71$; 95 % CI 0.41–0.92).

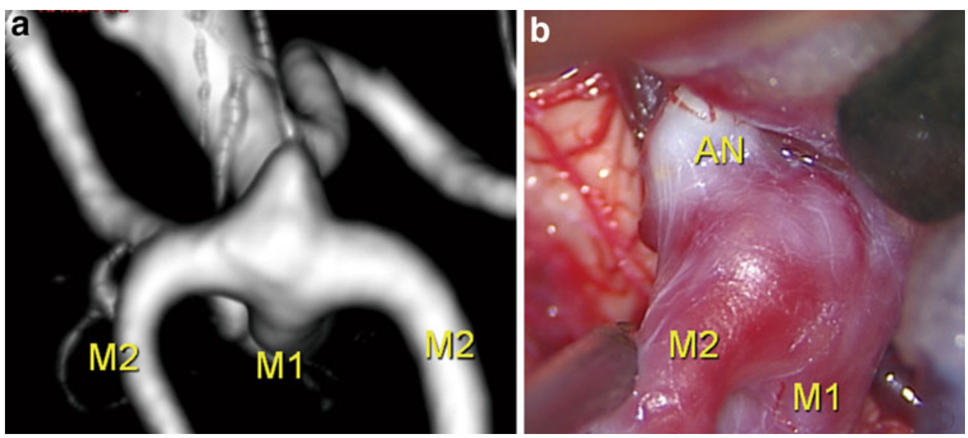

Fig. 1 A 56-year-old woman with a *right M1–M2* aneurysm. **a** CT angiogram (*right inferior view*) showing an *M1–M2* aneurysm. Both observers recorded the aneurysm as having no lobulation (grade 1), a wide neck, and no branches from the aneurysm (grade 1). *M1* portion of the middle cerebral artery, *M2* portion of the middle cerebral artery. **b** A *photograph* obtained during surgery confirmed CTA findings

Table 2 Summary of CTA and surgical findings for the aneurysm shape, neck and the relationship between the aneurysm and adjacent arteries in 40 patients with unruptured aneurysm

	CTA		Interobserver exact agreement	CTA[a]	Surgery	Exact agreement between CTA and surgical findings
	Reader 1	Reader 2				
Shape						
Grade 1	19	17	35/40	19	15	33/40
Grade 2	16	19	(88 %)	16	17	(83 %)
Grade 3	5	4		5	8	
Neck						
Narrow	9	8	32/40	9	8	30/40
Medium	23	25	(80 %)	23	26	(75 %)
Wide	8	7		8	6	
Relationship						
Grade 1	20	22	36/40	21	17	35/40
Grade 2	19	17	(90 %)	18	20	(88 %)
Grade 3	1	1		1	3	

[a] Consensus reading of the two readers

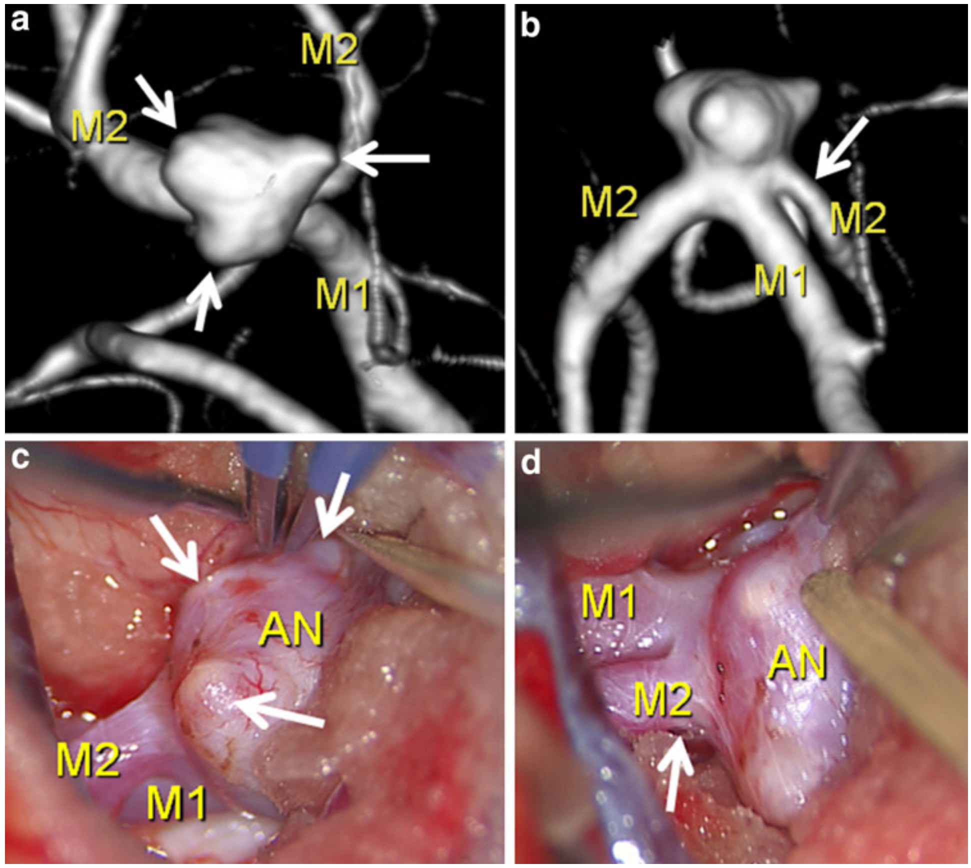

Fig. 2 A 46-year-old man with a *right M1–M2* aneurysm. **a** CT angiogram (*right inferior view*) showing three lobes (*arrows*). *M1* portion of the middle cerebral artery, *M2* portion of the middle cerebral artery. **b** CT angiogram (*inferior view*) clearly shows the relationship between the aneurysm and adjacent arteries. Both observers recorded the aneurysm as having 3 lobes (grade 3), a wide neck, and one M2 branch from the aneurysm neck (grade 2 *arrow*). **c** A *photograph* obtained during surgery shows multiple lobes of the aneurysm (grade 3 *arrows*). **d** A *photograph* obtained during surgery shows the relationship between the aneurysm and adjacent arteries. A wide neck is seen (grade 3); one M2 branch appears to derive from the aneurysm neck (grade 2 *arrow*)

Table 3 Interobserver agreement and agreement between CTA and surgical findings

	Aneurysm location	Aneurysm shape	Aneurysm neck	Relationship between the aneurysm and arterial branches
Interobserver agreement	1.0 (1.00–1.00)	0.822 (0.674–0.971)	0.801 (0.659–0.961)	0.831 (0.486–1.000)
Agreement between CTA and surgical findings	1.0 (1.00–1.00)	0.709 (0.533–0.886)	0.739 (0.543–0.935)	0.712 (0.412–0.921)

Data are κ statistics, with 95 % CIs in parentheses

There were no surgical complications in any of the 40 patients. In 40 cases with unruptured aneurysm, information obtained at CTA was reported as highly useful (grade 3) for surgical clipping in 38 cases. In the other 2 cases it was considered useful (grade 2); small perforators from the aneurysms in 2 cases that were not visualized on CTA images were confirmed at surgery (Fig. 3).

Discussion

Our study suggests that 320-detector CTA with single axial scanning is a reliable diagnostic tool for the localization and characterization of unruptured intracranial aneurysms. The agreement of CTA and surgical findings that served as the standard reference was excellent for the aneurysm location ($\kappa = 1.0$; 95 % CI 1.00–1.00) and good for the aneurysm shape ($\kappa = 0.71$; 95 % CI 0.53–0.89), the neck ($\kappa = 0.74$; 95 % CI 0.54–0.94), and the relationship between the aneurysm and adjacent arteries ($\kappa = 0.71$; 95 % CI 0.41–0.92).

Earlier studies showed that 4-, 16-, and 64-detector CTA with helical scanning was useful for pretreatment planning in patients with ruptured and unruptured intracranial aneurysms [2, 3, 5, 6]. In their prospective study Hoh et al. [6], who replaced DSA with a 4-detector CTA protocol for pretreatment planning, obtained promising results in 223 patients with ruptured and unruptured cerebral aneurysms. Our prospective study also yielded good results when we replaced DSA with 320-detector CTA studies for pretreatment planning in most patients with unruptured intracranial aneurysms.

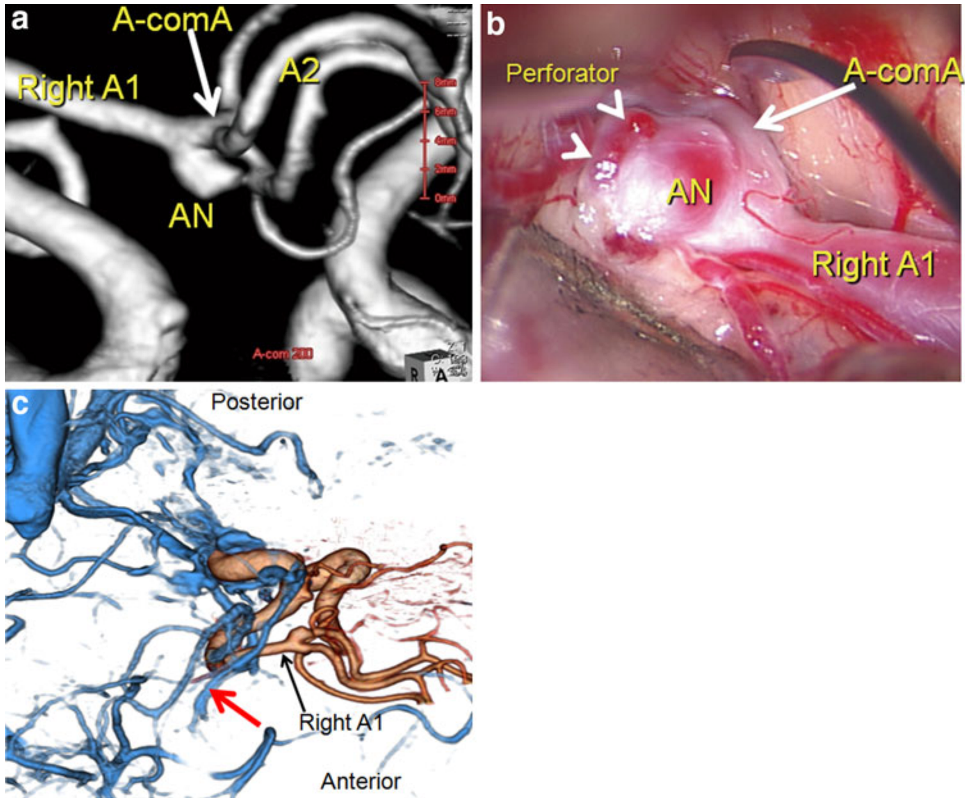

Fig. 3 A 59-year-old man with an anterior communicating artery (AcomA) aneurysm. **a** CT angiogram (*right oblique frontal view*) showing an AcomA aneurysm. Both observers recorded no branches from the aneurysm (grade 1). *A1* portion of the anterior cerebral artery, *A2* portion of the anterior cerebral artery. **b** A *photograph* obtained during surgery reveals a branch from the aneurysm dome (grade 3 *arrowheads*) that was not depicted by CTA. The CTA information was recorded as grade 2 for surgical clipping. **c** Surgical view of the CTA image shows the Sylvian vein (*red arrow*). This information is important for planning the surgical approach. Arteries are *red*, veins are *blue* (color figure online)

In 2 patients, small perforators from the aneurysms were not fully depicted on 320-detector CTA images. With respect to the voxel size, the diameter of perforators is often small and the spatial resolution of these images is not sufficiently high for their depiction; this is a disadvantage of 320-detector CTA. However, detailed intraoperative endoscopic inspection of the entire aneurysm provides information supplementary to 320-detector CTA findings.

To obtain sufficient preoperative information on intracranial aneurysms, CTA studies must be of high quality. Contrast enhancement of CT is affected by interacting factors related to the patient, the contrast medium, and the CT scanning parameters [15]. When the helical scan mode is used in 4-, 16-, and 64-detector row CT studies, step artifacts may arise due to patient motion during spiral acquisitions; these may result in scan failure [16]. This problem does not arise when 320-detector row CT scanners are used because their detector width of 16 cm covers the whole brain in a single axial rotation. In our study, motion artifacts did not interfere with image assessment possibly because all of our patients had unruptured intracranial aneurysms and their condition was good.

Advances in multidetector CT technology have raised issues with respect to the i.v. administration of contrast medium and CT scan timing [15]. In applying our 320-detector CT protocol we used a high-concentration contrast medium and a saline flush to increase vascular peak enhancement and to keep the bolus compact [17, 18]. Our scanning protocol was different from other helical CT protocols. Appropriate CTA scan timing is required for the adequate depiction of intracranial vasculatures because the arteriovenous transit time in the carotid artery-brain-jugular vein circulation is 6–10 s [19]. We started CT scanning at the arrival of the injected contrast medium at the circle of Willis to ensure acquisition during the arterial phase and we performed a 1.5-s single axial scan to obtain a sufficient vascular signal-to-noise ratio. Although the anatomic level for monitoring is usually the cervical ICA [2, 18], the fast scan time at 320-detector CT allowed setting the level at the intracranial arteries. Lastly, we acquired the venous structures without scanning delayed phase. The above scanning techniques (i.e., the contrast bolus-tracking technique at the circle of Willis and relatively long scanning time) also brought us successful visualization of intracranial venous structures. These combined techniques yielded high-quality CTA images and provided sufficient preoperative information.

As our scanning time was 1.5 s, our CT studies required a relatively small amount of contrast material. A reduction in its volume not only reduces the cost of the studies but it is advantageous in patients with renal insufficiency or patients who may require the administration of additional contrast material for other radiologic examinations [18, 20]. A single axial scan obtained on a 320-detector CT may also lower the radiation dose. The effective dose was significantly lower in patients undergoing coronary 320- than 64-detector CTA [21].

As the dose for 320-detector CTA with single axial scanning does not overlap with adjacent slices [22], the radiation exposure is considered to be theoretically lower than for 64-detector CTA with helical scanning. Mnyusiwalla et al. [23] reported radiation doses for acute stroke from a 64-detector CTA with helical scanning. In their report, the mean effective dose for acquisition of an unenhanced head CT and CTA from the arch to vertex was 2.7 ± 0.3 and 5.4 ± 2.2 mSv, respectively. In our study using 320-detector CT, the mean effective dose for the entire intracranial aneurysm studies was 3.1 ± 1.5 mSv. Although there are some differences in the scanning protocol between theirs and ours, the radiation dose of our CT protocol seems to be lower than theirs.

Our study has some limitations. First, we did not compare 320-detector CTA with intra-arterial DSA data. The gold standard using surgical findings might have induced some discrepancies in the agreement for aneurysm morphology. To comprehend the entire aneurysmal structure, intraoperative endoscopic examinations were used in this study. Therefore, we think that use of the surgical findings as the gold standard for this study was appropriate. Second, agreement regarding the size of aneurysms was not assessed in this study. It was difficult to accurately measure the size of aneurysms during the intracranial operation. Third, thrombus in an aneurysm was not assessed in this study. Although thrombus in an aneurysm was not observed on CTA in our cases, this information is important to determine the treatment strategy for intracranial aneurysms. Fourth, the referring neurosurgeons retrospectively assessed the usefulness for treatment decisions of the information provided by CTA. Although they did not perform their assessments immediately after surgery, they consensually recorded their assessments from the surgical findings. So, we believe that their bias was small.

In conclusion, our findings suggest that 320-detector CTA with single axial scanning is a reliable diagnostic tool for the preoperative evaluation of unruptured intracranial aneurysms. Information obtained from 320-detector CTA is highly useful for surgical treatment in most patients, although some small perforators deriving from the aneurysm may be missed.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Cloft HJ, Joseph GJ, Dion JE. Risk of cerebral angiography in patients with subarachnoid hemorrhage, cerebral aneurysms, and arteriovenous malformations: a meta-analysis. Stroke. 1999;30:317–20.
2. Papke K, Kuhl CK, Fruth M, et al. Intracranial aneurysms: role of multidetector CT angiography in diagnosis and endovascular therapy planning. Radiology. 2007;244:532–40.
3. Li Q, Lv F, Li Y, Luo T, Li K, Xie P. Evaluation of 64-section CT angiography for detection and treatment planning of intracranial aneurysms by using DSA and surgical findings. Radiology. 2009;252:808–15.
4. Westerlaan HE, van Dijk JM, Jansen-van der Weide MC, et al. Intracranial aneurysms in patients with subarachnoid hemorrhage: CT angiography as a primary examination tool for diagnosis—systematic review and meta-analysis. Radiology. 2011;258:134–45.
5. Anderson GB, Steinke DE, Petruk KC, Ashforth R, Findlay JM. Computed tomographic angiography versus digital subtraction angiography for the diagnosis and early treatment of ruptured intracranial aneurysms. Neurosurgery. 1999;45:1315–20.
6. Hoh BL, Cheung AC, Rabinov JD, Pryor JC, Carter BS, Ogilvy CS. Results of a prospective protocol of computed tomographic angiography in place of catheter angiography as the only diagnostic and pretreatment planning study for cerebral aneurysms by a combined neurovascular team. Neurosurgery. 2004;54:1329–40.
7. Moran CJ. Aneurysmal subarachnoid hemorrhage: DSA versus CT angiography—is the answer available? Radiology. 2011;258:15–7.
8. Hayakawa M, Maeda S, Sadato A, et al. Detection of pulsation in ruptured and unruptured cerebral aneurysms by electrocardiographically gated 3-dimensional computed tomographic angiography with a 320-row area detector computed tomography and evaluation of its clinical usefulness. Neurosurgery. 2011;69:843–51.
9. Luo Z, Wang D, Sun X, et al. Comparison of the accuracy of subtraction CT angiography performed on 320-detector row volume CT with conventional CT angiography for diagnosis of intracranial aneurysms. Eur J Radiol. 2012;81:118–22.
10. Sun G, Ding J, Lu Y, et al. Comparison of standard- and low-tube voltage 320-detector row volume CT angiography in detection of intracranial aneurysms with digital subtraction angiography as gold standard. Acad Radiol. 2012;19:281–8.
11. Nahed BV, DiLuna ML, Morgan T, et al. Hypertension, age and location predict rupture of small intracranial aneurysms. Neurosurgery. 2005;57:676–83.
12. Yamashiro S, Nishi T, Koga K, et al. Postoperative quality of life of patients treated for asymptomatic unruptured intracranial aneurysms. J Neurosurg. 2007;107:1086–91.
13. Sonobe M, Yamazaki T, Yonekura M, Kikuchi H. Small unruptured intracranial aneurysm verification study: SUAVe study, Japan. Stroke. 2010;41:1969–77.
14. Matsuki M, Tanikake M, Kani H, et al. Dual-phase 3D CT angiography during a single breath-hold using 16-MDCT: assessment of vascular anatomy before laparoscopic gastrectomy. AJR Am J Roentgenol. 2006;186:1079–85.
15. Bae KT. Intravenous contrast medium administration and scan timing at CT: considerations and approaches. Radiology. 2010;256:32–61.
16. Barrett JF, Keat N. Artifacts in CT: recognition and avoidance. Radiographics. 2004;24:1679–91.
17. Nagahata M, Abe Y, Ono S, et al. Attenuation values of the intracranial arterial and venous vessels by bolus injection of various contrast agents: a study with a single-detector helical CT scanner. Radiat Med. 2007;25:89–93.
18. Tamura Y, Utsunomiya D, Sakamoto T, et al. Reduction of contrast material volume in 3D angiography of the brain using MDCT. AJR Am J Roentgenol. 2010;195:455–8.
19. Kim JK, Farb RI, Wright GA. Test bolus examination in the carotid artery at dynamic gadolinium-enhanced MR angiography. Radiology. 1998;206:283–9.
20. Nakaura T, Awai K, Maruyama N, et al. Abdominal dynamic CT in patients with renal dysfunction: contrast agent dose reduction

with low tube voltage and high tube current-time product settings at 256-detector row CT. Radiology. 2011;261:467–76.
21. Khan A, Khosa F, Nasir K, Yassin A, Clouse ME. Comparison of radiation dose and image quality: 320-MDCT versus 64-MDCT coronary angiography. AJR Am J Roentgenol. 2011;197:163–8.
22. Kobayashi M, Koshida K, Suzuki S, Katada K. Evaluation of geometric efficiency and radiation exposure in z-axis for volume scan. Radiat Prot Dosimet. 2011;143:63–8.
23. Mnyusiwalla A, Aviv RI, Symons SP. Radiation dose from multidetector row CT imaging for acute stroke. Neuroradiology. 2009;51:635–40.