Cerebral CT angiography using a small volume of concentrated contrast material with a test injection method: optimal scan delay for quantitative and qualitative performance

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Objectives: The objective of this study was to determine the optimal scan delay quantitatively and qualitatively in cerebral CT angiography (CTA) with a test injection method at the circle of Willis (cW).

Methods: 66 consecutive patients suspected of having unruptured intracranial aneurysms underwent CTA using 40 ml of 370 mg iodine ml⁻¹ contrast material (CM). After the time until CM arrival at the cW (T_{cW}) was calculated, scan delay was divided into three groups according to T_{cW} and scan duration (SD) between the second cervical vertebra and cW as follows: $[(T_{cW}+6)-SD]$ in 21 patients (Group A); $[(T_{cW}+8)-SD]$ in 23 patients (Group B); and $[(T_{cW}+10)-SD]$ in 22 patients (Group C). Arterial and venous attenuation in the intracranial vessels was measured. Mean attenuation values were compared quantitatively. The arterial enhancement and venous overlap at the cW and above the cW were qualitatively compared among the three groups.

Results: Mean arterial attenuation in Groups B and C was significantly higher than that in Group A. Mean venous attenuation in Group C was significantly higher than those in Groups A and B. Arterial enhancement above the cW showed a significant difference between Groups A and C, and at the cW between Groups A and B, and Groups A and C. There was a significant difference in venous overlap among the three groups, except for that at the cW between Groups B and C.

Conclusions: Setting scan delay as $[(T_{cW}+8)-SD]$ s can produce the best performance both quantitatively and qualitatively.

Received 16 May 2011
Revised 30 August 2011
Accepted 31 August 2011

DOI: 10.1259/bjr/31882420

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Radiology

Because brain imaging is being performed more frequently with modern CT and MRI equipment, the detection of asymptomatic unruptured intracranial aneurysms has increased [1, 2]. As CT angiography (CTA) with a 64-slice multidetector CT (64-MDCT) system has been widely accepted as a primarily non-invasive method for detection of cerebral aneurysms [3–6], it may play a role in screening asymptomatic patients by imaging unruptured aneurysms [1].

With the fast scanning capability of MDCT, reduction of contrast material (CM) and distinction of arterial and venous structures are expected [7]. By contrast, an off-timing scan can increase the risk of suboptimal arterial enhancement and marked venous overlay; therefore, CTA with a small volume and short acquisition time requires precise scan timing [8].

Recent reports have indicated that the acquisition time between the skull base and vertex is <5 s using a 64-MDCT system, and the total volume of CM is 50–80 ml [3–6]. However, to our knowledge, there are no previous reports of studies using <50 ml of CM, and no reports that have quantitatively and qualitatively assessed the scan

delay to capture the maximal arterial enhancement with the minimal venous overlap.

In our previous experience, cervical CTA using 40 ml of 370 mg iodine (I) ml⁻¹ CM at 4.0 ml s⁻¹ can provide similar arterial attenuation up to 400 HU and small venous attenuation compared with CTA using 60 ml of 300 mg I ml⁻¹ CM [9]; therefore, we hypothesised its high efficiency of an acceptable intracranial CTA. Consequently, this study analysed whether cerebral CTA using the same 40 ml of 370 mg I ml⁻¹ CM can provide adequate arterial attenuation, and investigated an optimal scan delay for the quantitative and qualitative performance.

Methods and materials

Patients

We retrospectively reviewed the cerebral CTA data of 66 consecutive patients who had undergone imaging on a 64-MDCT scanner (LightSpeed® VCT; GE Healthcare, Milwaukee, WI) between December 2008 and July 2010. Our study cohort included 25 males and 41 females (age range 35–81 years; mean age 63.3 years). The inclusion criteria for this study were: (1) patients with known or suspected unruptured intracranial aneurysms for

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preliminary neuro-intervention; (2) patients with venous access through the right antecubital vein to mitigate venous reflex of CM into the cervical veins; (3) patients without severe heart failure; and (4) patients with no previous allergic reaction to iodinated CM, renal insufficiency (serum creatinine level of 1.5 mg dl^{-1}) or previous history of asthma.

The CT examinations were divided into three protocols according to when they were performed. The first set of CTA examinations was performed in 22 patients between December 2008 and March 2009 (Group A). The second set of CTA examinations was performed in 23 patients between April 2009 and November 2009 (Group B). The third set of CTA examinations was performed in 21 patients between December 2009 and July 2010 (Group C). All patients had undergone cerebral CTA using 40 ml of 370 mg I ml^{-1} iopamidol (Iopamiron® 370; Bayer Pharmacy, Osaka, Japan) CM followed by 25 ml of saline flush [7]. Time (T_{cW}) until CM arrival at the circle of Willis (cW) was calculated with a test injection method. Scan duration (SD) between the second cervical vertebra and cW was recorded as the scan range between the second cervical vertebra and cW divided by table speed. Scan delay was defined as the interval until scanning was initiated after CM administration. According to an empirical aortic enhancement curve with a short injection duration [10], three different timings initiated at 2 s intervals were determined as follows: $[(T_{\text{cW}}+6)\text{--SD}]$ in Group A, $[(T_{\text{cW}}+8)\text{--SD}]$ in Group B, and $[(T_{\text{cW}}+10)\text{--SD}]$ in Group C. The other parameters, including the CM volume and concentration, injection rate and saline flush, remained constant in the three groups. None of the patients was excluded from analysis, and there were no technical problems or extravasation of CM. Age (years), sex (male/female), body weight (kg) and height (cm) were recorded as characteristic parameters (Table 1). All data are shown as mean value $\pm$ standard deviations.

Approval for this study was obtained from the institution's review board for human studies, and informed consent was waived for this retrospective review of clinical records.

CT protocol

First, the test bolus technique was performed at the cW to obtain accurate information about CM arrival time in the individual circulation. After a 20-gauge catheter was placed into the right antecubital vein, 20 ml of CM

followed by 15 ml of saline flush was administered at a flow rate of 4.0 ml s^{-1} using a double injector (Dual-Shot® DX Injector; Nemoto-kyorindo, Tokyo, Japan). Patients were placed in a supine position with their arms alongside the body and their heads tilted slightly forward.

On the basis of our earlier findings, single-level dynamic CT scans were performed with the gantry tilted parallel to the anterior skull base (Figure 1). This range could scan the right internal carotid artery (ICA) and sigmoid sinus (SS) with reference to the anatomy at the skull base. After scanning anterior and lateral localiser images, five slice scans (5 mm section thickness) were preliminarily obtained to determine the scanning position for those reference vessels on single-level dynamic CT scans. Next, dynamic CT scans (5 mm section thickness) were acquired every 2 s, starting 8 s after intravenous administration of the test bolus. Scans were continued until CM appeared as hyperattenuating spots in these vessels. The time attenuation curves at the right ICA and SS were then generated by placing small circular regions of interest (ROIs) at sites without calcification of the arterial wall and temporal bone ($0.5\text{--}1.0 \text{ mm}^2$). T_{cW} and time until CM arrival in the right SS (T_{SS}) were selected as an increase of 15 HU or more from the baseline for the arterial and venous ROIs, respectively. When the time attenuation curve showed a rapid increase from the initial scan, 8 s was chosen as T_{cW} .

Scan coverage ranged between the second cervical vertebra and the vertex. The table feed was 53.1 mm s^{-1} for high spatial resolution of isotropic data (collimation $64 \times 0.625 \text{ mm}$; rotation time 0.4 s rot^{-1} ; pitch 0.531 in a caudocranial scan direction). The other acquisition parameters were as follows: tube voltage 120 kVp, tube current 335 mA, matrix of 512×512 , field of view 18–22 cm, section thickness 0.625 mm and reconstruction interval 0.312 mm (50% overlapping). CT examinations were performed at least 5 min after the end of the test bolus injection in order to minimise venous attenuation by the effect of the test bolus injection. T_{cW} (seconds), T_{SS} (seconds) and SD (seconds) were also recorded as characteristic parameters (Table 1). All data are shown as mean value $\pm$ standard deviation.

Image analysis

To analyse the entire cerebral vascular anatomy and pathology, source images (slice thickness of 0.312 mm), which were loaded on a separate workstation

Table 1. Patient characteristics and scan parameters

Parameter	Group A	Group B	Group C	p-value
Number of patients	21	23	22	
Sex (male/female)	8/13	10/13	7/15	0.73
Age (years)	64.4 ± 12.9	61.4 ± 14.5	65.0 ± 11.3	0.54
Body weight (kg)	58.5 ± 9.3	58.4 ± 9.9	57.8 ± 7.7	0.90
Height (cm)	157.5 ± 8.1	159.4 ± 7.0	159.0 ± 7.5	0.88
T_{cW} (s)	13.5 ± 3.1	12.8 ± 2.0	13.5 ± 1.7	0.68
T_{SS} (s)	19.6 ± 3.7	18.7 ± 2.2	19.2 ± 2.7	0.68
SD (s)	2.1 ± 0.3	2.2 ± 0.4	2.1 ± 0.4	0.47

SD, scan duration; T_{cW} , time until contrast material arrival at the internal carotid artery; T_{SS} , time until contrast material arrival in the right sigmoid sinus.

Data are given as number and mean $\pm$ standard deviation.

Figure 1. A test bolus technique at the circle of Willis (cW) in an 84-year-old male. (a, b) Single level dynamic CT scan with tilted gantry parallel to the anterior skull base (white line) at the level of the cW scanned the right internal carotid arteries (rt ICA) and right sigmoid sinus (rt SS). Scans were continued until the contrast material appeared as hyperattenuating spots in the right ICA (2) and SS (1), respectively. (c) Time attenuation curves in the rt ICA and SS were generated by placing small circular regions of interest (ROIs). Time until contrast material arrival at the cW (T_{cw}) was selected at right ICA with an increase as 15 HU over baseline for the arterial ROI. Time until contrast material arrival (T_{ss}) at the rt SS was selected at an increase as 15 HU over baseline for the venous ROI.

(Advantage[®] 4.3; GE Healthcare) with a window/level setting of 700/200 HU [11], were utilised in cine mode. For qualitative evaluation of post-processing three-dimensional images, axial and coronal maximum-intensity projection (MIP) with a sliding thin slab (6 mm slab thickness with 3 mm increment) was utilised for analysis of the intracranial arterial and venous system.

Quantitative analysis

Source images were used to evaluate arterial and venous attenuation. One radiologist (KK) measured arterial attenuation values at seven points, including the carotid artery, cerebral artery and vertebrobasilar artery. ROIs were placed at the following points: (1) distal vertebral artery; (2) distal basilar artery; (3) ICA at the pyramidal segment; (4) ICA at the cavernous segment; (5) ICA at the communicating segment; (6) middle cerebral artery (MCA) at the M1 segment; and

(7) anterior cerebral artery (ACA) at the A1 segment. When a vessel of interest was obscured by severe dense calcification of the arterial wall or congenital hypoplasia, the attenuation values of the affected vessel segments were not measured. As an index of adequate CT attenuation, arterial attenuation greater than 300 HU was indicated in the cervical artery [11]. Therefore, we selected values greater than 300 HU in the cerebral artery as the optimal attenuation, and the number of measurements below 300 HU was counted.

In addition, venous attenuation values were measured at three points: the straight sinus, sigmoid sinus and cavernous sinus. An attempt was made to place ROIs near the edge in order to trace the venous lumen fully, including any deposited CM. Each ROI ranged from 1 to 4 mm². To compare the magnitude of contrast columns among these three groups, the mean arterial attenuation was calculated from ROI 1 to ROI 7 in the arterial system, and mean venous attenuation was calculated from ROI 1 to ROI 3 in the venous system (Table 2).

Table 2. Quantitative evaluation of intracranial artery and vein

Parameter	Group A	Group B	Group C	p-value
Arterial systems				
Distal vertebral artery	308 ± 85	339 ± 76	434 ± 70	<0.01
Distal basilar artery	334 ± 78	339 ± 79	421 ± 56	<0.01
ICA at pyramidal segment	379 ± 75	456 ± 75	494 ± 74	<0.01
ICA at cavernous segment	398 ± 79	457 ± 69	480 ± 76	<0.01
ICA at communicating segment	394 ± 82	448 ± 70	445 ± 81	0.001
MCA at M1 segment	363 ± 73	421 ± 75	433 ± 75	0.005
ACA at A1 segment	341 ± 85	378 ± 61	392 ± 62	0.009
Mean attenuation	353 ± 75	412 ± 64	426 ± 60	<0.01
Venous systems				
Straight sinus	151 ± 59	256 ± 73	348 ± 88	<0.01
Sigmoid sinus	126 ± 46	221 ± 77	271 ± 86	<0.01
Cavernous sinus	112 ± 57	200 ± 72	263 ± 101	<0.01
Mean attenuation	125 ± 48	216 ± 62	292 ± 78	<0.01

ACA, anterior cerebral artery; ICA, internal carotid artery; MCA, middle cerebral artery.

Data are mean ± standard deviation.

Qualitative analysis

Two experienced radiologists (NO and TH) evaluated image quality, reaching a consensus for each image. First, arterial enhancement of the intracranial main arteries and small branches was assessed qualitatively using a four-point scale: 1, poor; 2, acceptable; 3, good; and 4, excellent. Main intracranial arteries were indicated as follows: ICA, ACA, MCA, posterior cerebral artery (PCA), vertebral artery and basilar artery. Small branches were indicated as the superior cerebral artery, ophthalmic artery, anterior and posterior communicating artery, MCA at M2 and M3 segment, and ACA at A2 and A3 segment. Next, the two radiologists were asked to rate the quality of images showing venous overlap between the arterial and venous structures at the cW and above the cW, using axial and coronal thin-slab MIP images (6 mm slab thickness with 2 mm increments) using a four-point scale [12]: 1, indiscernible overlap exists; 2, although minimal overlap (the venous attenuation is much smaller than arterial attenuation) exists, the arterial lumen was easily recognised; 3, although moderate overlap (venous attenuation is less than arterial attenuation) exists, distinction of the arterial lumen from the venous lumen is not difficult; and 4, as severe overlap (venous attenuation is close to arterial attenuation) exists, distinguishing the arterial lumen from the venous lumen requires careful attention (Figures 2–4). The region at the cW consists of vertebral arteries, basilar artery, intracranial internal arteries, MCA at the pre-M1 bifurcation and ACA at the A1 segment. The region above the cW consists of MCA at the post-M1 bifurcation, and ACA at the A2 and A3 segments.

Statistical analysis

Statistical analysis was performed using SPSS® v. 15.0 (SPSS, Chicago, IL). Characteristic parameters, and arterial and venous attenuation values were compared

using one-way analysis of variance to investigate intergroup differences among the three groups (Tables 1 and 2). When the overall differences were significant, *post hoc* analysis was performed using the Tukey–Kramer test for multiple comparisons among the three groups (Figure 5). Sex distribution for the three protocols was analysed by χ^2 test. For qualitative analysis, the Kruskal–Wallis test was applied to examine intergroup differences among the three groups (Table 3), and differences between two groups were then assessed by the Mann–Whitney *U*-test (Table 4). Probability values below 0.05 were considered significant.

Results

Table 1 shows that patient characteristics were not significantly different among the three groups.

In Table 2, multiple-group comparisons of mean arterial attenuation in the arterial system and mean venous attenuation in the venous system show significant differences ($p < 0.01$). Mean attenuation values in the arterial system were 353 ± 75 , 412 ± 64 and 426 ± 60 HU for Groups A, B and C, respectively. *Post hoc* tests confirmed that although there was no significant difference between Groups B and C ($p = 0.234$), there were significant differences ($p < 0.01$) between Groups A and B and between Groups A and C (Figure 5a). The mean attenuation values in the venous system were 125 ± 48 , 216 ± 62 and 292 ± 78 HU for Groups A, B and C, respectively, and *post hoc* tests confirmed that there were no significant differences ($p < 0.01$) between groups A and B, A and C, or B and C (Figure 5b).

With regard to the measurement of arterial attenuation, the affected arterial segments with obscuration hampered analysis in 1.9% (5/273) of all measurements in Group A, 1.1% (3/299) of all measurements in Group B and 2.4% (7/286) of all measurements in Group C. In

Figure 2. Cerebral CT angiography in a 77-year-old female with an aneurysm (arrow) at the M1 segment of the left middle cerebral artery. (a, b) Coronal and (c, d) axial maximum-intensity projection images showed excellent arterial enhancement (score 4) at the circle of Willis (cW) and above the cW, and minimal venous overlay (score 2) at the cW and above the cW.

Figure 3. Cerebral CT angiography in a 68-year-old female with an aneurysm (arrow, c) at the communicating segment of the right ICA. (a, b) Coronal and (c, d) axial maximum-intensity projection images showed excellent arterial enhancement (score 4) and moderate venous overlay (score 3) at the circle of Willis (cW), and moderate arterial enhancement (score 3) and severe venous overlay (score 4) above the cW.

Group A, arterial attenuation was lower than 300 HU in 22.9% (62/268) of all measurements, which was found in 12 of 21 patients (57.1%). In Group B, arterial attenuation was lower than 300 HU in 22.9% (9/296) of all measurements, which was found in 5 of 23 (21.7%) patients. In Group C, arterial attenuation was lower than 300 HU in 22.9% (5/279) of all measurements, which was found in 4 of 22 (18.2%) patients.

On qualitative analysis of arterial enhancement and venous overlap (Table 3), multiple-group comparisons demonstrated significant differences ($p < 0.01$). With regard to two-group comparison (Table 4), arterial enhancement at the cW showed a significant difference between Groups A and B ($p = 0.034$), and A and C

($p = 0.001$), and that above the cW showed a significant difference in Groups A and C ($p = 0.017$), although comparison among the other groups did not demonstrate a significant difference. Venous overlap at the cW and above the cW was significantly different among groups, although that at the cW did not show a significant difference between Groups B and C ($p = 0.082$).

Discussion

Currently, three techniques are used for CTA scanning—namely, a fixed delay, bolus triggering and the test bolus method [13]. Because a fixed delay is based on

Figure 4. Cerebral CT angiography in a 59-year-old male with an aneurysm (arrow, c) at the communicating segment of the right ICA. (a, b) Coronal and (c, d) axial maximum-intensity projection images showed moderate arterial enhancement (score 3) and indiscernible venous overlay (score 1) at the circle of Willis (cW), and acceptable arterial enhancement (score 2) and minimal venous overlay (score 2) above the cW.

Figure 5. (a) Comparison of the mean attenuation values for the arterial system among the three groups. In the box-and-whisker plots, although there was no significant difference between Groups B and C ($p=0.234$), there were significant differences ($p<0.01$) between Groups A and B, and between Groups A and C. (b) Comparison of mean attenuation values for the venous system among the three groups. In box-and-whisker plots, there were no significant differences ($p<0.01$) between Groups A and B, A and C, or B and C. In boxes, upper and lower margin and middle horizontal lines represent upper quartiles (UQs), lower quartiles (LQs) and medians of data, respectively. Upper and lower ends of vertical lines and circles represent upper extremes [$UQ+1.5 \times (\text{interquartile range})$], lower extremes [$LQ-1.5 \times (\text{interquartile range})$] and outliers of data, respectively.

previous experience, it has not been reliable in all patients owing to individual variations in blood flow. The bolus triggering technique has various triggering thresholds ranging from 100 to 250 HU at various reference vessels among the cervical or intracranial ICA, and variations in the inherent delay in moving the table to its starting position. However, the test bolus method can accurately demonstrate individual circulation, and may be appropriate for CTA protocol using a small volume [8, 14]. Concentrated CM at a rapid injection rate was standardised in this study, because we believe that high arterial attenuation with small venous attenuation can decrease venous overlap [9, 12]. Therefore, the optimal delay for cerebral CTA using a small volume of CM with the test bolus method will be investigated quantitatively and qualitatively.

Regarding CM volume, there have been two reports using a 16-MDCT system with 50 ml of CM at 3.0 ml s^{-1} with the bolus triggering method [15, 16]. The present study with a 64-MDCT system using 40 ml of concentrated CM at 4.0 ml s^{-1} provides greater arterial attenuation and less venous overlap than those in previous reports.

Although venous enhancement is not a crucial factor in the detection of cerebral aneurysms, except for extensive enhancement of the cavernous sinus [8], short scan

times in a 64MDCT system allow clearly different attenuation values for arteries and veins. As Pozzi-Mucelli et al have indicated, the detection of cerebral aneurysm by CTA is strongly dependent on radiologist experience in two- and three-dimensional reconstructions on the workstation, such as multiplanar reconstruction, MIP and volume rendering, and these elaborations may be time consuming, ranging from 10 to 30 min, depending on operator experience [3]. They also indicated that attempts must be made to make elaborations similar to catheter-based angiography projections, and thus an angiographic background is a good starting point for performing a good job on the workstation. We consider that minimal venous overlap on CTA can save time in establishing a diagnosis by omitting additional viewing of source images, and this can be effective for post-processing of volume-rendered images and segmentation [12].

With regard to quantitative assessment, arterial segments greater than 300 HU were found in 91.0% (767/843) of all measurable segments. Therefore, CTA protocol using 40 ml of CM achieved adequate contrast enhancement, although there is a question as to whether an attenuation value greater than 300 HU is imperative on cerebral CTA. To the authors' knowledge, there has not been any report evaluating the optimal attenuation

Table 3. Qualitative assessment for the arterial and venous system

Parameter	Group A	Group B	Group C	p-value
Arterial enhancement				
Circle of Willis	3.4 ± 0.4	3.8 ± 0.4	3.9 ± 0.2	0.002
Above the circle of Willis	3.3 ± 0.4	3.7 ± 0.5	0.8 ± 0.6	0.039
Venous overlap				
Circle of Willis	1.8 ± 0.5	2.3 ± 0.6	2.7 ± 0.6	<0.01
Above the circle of Willis	2.3 ± 0.6	3.1 ± 0.7	3.4 ± 0.7	<0.01

Data are mean $\pm$ standard deviation.

Table 4. Comparison of the qualitative evaluation among the three groups

Parameter	Circle of Willis	Above the circle of Willis
Arterial enhancement		
Group A vs Group B	0.034	0.261
Group A vs Group C	0.001	0.017
Group B vs Group C	0.187	0.161
Venous overlap		
Group A vs Group B	0.002	<0.01
Group A vs Group C	<0.01	<0.01
Group B vs Group C	0.082	0.040

value. In Group A, arterial segments less than 300 HU were found in 22.9% (62/268), and quantitative evaluation of arterial attenuation was significantly lower than that in other groups; therefore, it was considered that the scan delay time of this group was the earliest of the three groups. In Group C, the mean venous attenuation was greatest among the three groups, although the mean arterial attenuation was largest. With regard to qualitative analysis, there was no significant difference between Groups B and C in arterial enhancement at the cW and above the cW. Moreover, there was no significant difference between Groups B and C in venous overlap at the cW. Therefore, it was considered that CTA in Group B showed the optimal performance quantitatively and qualitatively among these three groups. As mean T_{cW} was 13.2 s and mean SD was 2.2 s in all patients, the optimal scan delay should be started approximately 19 s after the initiation of injection. Even for a small volume of CM administered at a high injection rate and a fast acquisition scan using the 256 or 320 MDCT system, the results of the present study might be useful to reduce the number of scan times.

Regarding qualitative analysis, Group B showed the best performance with the maximal arterial enhancement and medium venous overlap. Qualitatively, venous overlap above the cW in Group B was smaller than that in Group C. Because unruptured cerebral aneurysms rarely occur above the cW, dividing vessels into those at and above the cW may be questionable. However, there is subjective differentiation of the vessels between those at and above the cW. Limiting venous overlap of the cortical veins above the cW can make it easier to detect small aneurysms at the distal branches of the MCA, such as infectious intracranial aneurysms [17].

There are several limitations in the present study. First, the three groups were not randomly selected, and this was a retrospective study. Therefore, further studies are required to validate the present results in a prospective and randomised manner. Despite being a retrospective study, Groups A, B and C did not show any significant difference in patient characteristics: sex, age, body weight and height. When individual circulation and cerebral haemodynamics were considered, T_{cW} and T_{SS} did not show differences among the three groups either. Second, only patients with known or suspected cerebral aneurysms were selected for this study because many patients also had normal cerebral and cervical arteries without suspicion of atherosclerotic sclerosis, and none of the patients had any neurological symptoms. The

technique used in this study, however, will allow evaluation of arterial stenosis in the intracranial arteries. Third, the patient population was small and females were predominant. Considering that Japanese patients tend to weigh approximately 60 kg or less, the ranges and mean body weights were smaller than those of people in North America and Europe [18]. Thus, the 40 ml CTA protocol may correspond to a CTA protocol using approximately 60 ml of CM with an additional delay time of $[(T_{cW}+10)-SD]$ in larger patients. Fourth, only patients with normal cardiac output were selected. When cardiac output decreases, the circulation of CM slows. CM bolus arrives slowly, resulting in delayed CM bolus arrival and delayed peak arterial enhancement [19]. Thus, optimal scan delay should be set longer than $[(T_{cW}+8)-SD]$.

In conclusion, setting scan delay as $[(T_{cW}+8)-SD]$ seconds (where T_{cW} represents time until contrast material arrival at the internal carotid artery) for cerebral CTA using 40 ml of highly concentrated CM can produce the best performance quantitatively and qualitatively.

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