High-Resolution Magnetic Resonance Imaging (HR-MRI) Evaluation of the Distribution and Characteristics of Intra-Aneurysm Thrombosis to Improve Clinical Diagnosis of Thrombotic Intracranial Aneurysm

Yan Gu*  
Chongchang Miao*  
Aimin Li  
Yonggang Zhang  
Jian Xu

* Yan Gu and Chongchang Miao contributed equally to this work and should be considered co-first authors.

Corresponding Author: Aimin Li, e-mail: lamdoctor@163.com

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Background:
We aimed to analyze the related factors of intracranial anterior circulation saccular artery thrombosis and its characteristics on high-resolution magnetic resonance imaging (HR-MRI) images to provide a basis for neurosurgeons to select the precise treatment strategy for thrombotic intracranial aneurysms (TIA).

Material/Methods:
This retrospective analysis included 136 patients with unruptured intracranial anterior circulation artery aneurysms who underwent HR-MRI. The 136 aneurysms were divided into thrombus (41) and non-thrombus (95) groups. Single factor analysis of morphological and clinical indicators were conducted to select meaningful indicators for logistic regression analysis; the optimal diagnostic threshold was calculated through ROC curve analysis. The location and signal characteristics of thrombi were analyzed to inform clinical treatment.

Results:
Single factor analysis revealed significant differences in patient age, aneurysm size, aneurysm neck, aspect ratio, size ratio, and hyperlipidemia between the 2 groups (P<0.05). Multi-factor regression analysis demonstrated that aneurysm size (OR=2.180) and aspect ratio value (OR=7.495) were correlated with intracranial thrombosis. ROC curve analysis showed that for aneurysms larger than 8 mm, the sensitivity and specificity of TIA prediction were 83% and 93%, respectively. For aneurysms with aspect ratio values greater than 2.5, sensitivity and specificity of TIA prediction were 75% and 95%, respectively. The proportion of aneurysm wall enhancement and clinical symptoms in the thrombus group was significantly higher than that in the non-thrombus group.

Conclusions:
Intracranial unruptured aneurysms with the size larger than 8 mm or with aspect ratio values higher than 2.5 indicated the possible formation of thrombosis in the aneurysm.

Keywords:
Intracranial Aneurysm • Magnetic Resonance Imaging • Thrombosis

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Authors’ Contribution:
ABCEG 1 Yan Gu*  
ABCD 1 Chongchang Miao*  
ABDF 2 Aimin Li  
BD 1 Yonggang Zhang  
CDF 1 Jian Xu

1 Department of Radiology, Lianyungang Clinical College of Nanjing Medical University, Lianyungang, Jiangsu, PR China  
2 Department of Neurosurgery, Lianyungang Clinical College of Nanjing Medical University, Lianyungang, Jiangsu, PR China

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Background

Thrombotic intracranial aneurysms (TIA) account for about 5% to 9% of intracranial aneurysms, and the age of onset is not significantly different from that of common aneurysms, which occur most often in people aged 40 to 60 years old [1]. Studies have shown that large or giant thrombotic aneurysms account for about 83% of total TIA, while about 60% of giant aneurysms are accompanied by thrombosis [2]. Thus, it is thought that the formation and growth of intracranial thrombi is one of the causes of giant aneurysms [3]. Since TIA are mainly large or giant aneurysms, they can occupy significant areas of the brain. In addition, some of them can continue to grow, leading to compression of surrounding nerve tissues and corresponding clinical symptoms. The 5-year cumulative rupture rate of anterior circulation aortic aneurysms is 40% [4]. Thus, TIA usually need surgical resection. With the improvement of microsurgery and intraoperative monitoring technology, the mortality rate of small intracranial aneurysms has dropped to about 2% [5]. However, owing to the large size of TIA, as well as to the thrombosis and irregular structure, the complexity of surgery is greatly increased. The treatment outcome is also suboptimal compared with that of ordinary aneurysms, posing a severe challenge for neurosurgeons. To treat TIA more effectively, an accurate examination method is needed to determine the true outer perimeter of the aneurysm and the distribution range of the thrombus within the aneurysm cavity.

Digital subtraction angiography is the criterion standard for the diagnosis of intracranial aneurysms but cannot show the complete size of a TIA, and the technique is invasive. Computed tomographic angiography (CTA) is the most commonly used examination method for intracranial aneurysms, but detecting the thrombus in aneurysms is challenging with this method. Thus, these 2 aneurysm detection methods can lead to the missed diagnosis or misdiagnosis of TIA. High-resolution magnetic resonance imaging (HR-MRI) with the black-blood contrasting sequence has been successfully applied to accurately display vascular wall plaques in the head and neck regions [6]. It is the current criterion standard for vascular wall plaque imaging and plays a decisive role in the formulation of clinical treatment plans for head and neck plaques [7]. As for diagnosing aneurysms, HR-MRI with the aneurysm wall enhancement (AWE) technique has been used to predict the rupture risk of the aneurismal wall [8-10]. However, there are few reports on the use of MRI for TIA diagnosis. HR-MRI will not only identify the true perimeter of the aneurysm, but will clearly show the morphology and distribution of the aneurysm wall and thrombus, as well as the thrombotic vasa vasorum without the interference of blood flow. Intracranial aneurysms occur more frequently in the anterior circulation with predominantly saccular aneurysms, while dissecting and fusiform aneurysms are often associated with the posterior circulation. There are also significant hemodynamic differences between the anterior and posterior circulations. Hence, this study is focused on analyzing the factors relating to anterior circulation TIA through HR-MRI and the distribution and signal characteristics of thrombi in aneurysms to provide the basis for neurosurgeons to select accurate treatments for TIA.

Material and Methods

Research Subjects

All cases in this study were approved by the ethics committee. In this study, we retrospectively analyzed patients in our hospital from May 2017 to May 2021 who had undergone HR-MRI of the vessel wall, with unruptured intracranial anterior circulation arteries inadvertently discovered during examination.

The inclusion criteria were as follows: (1) the size of single-saccular unruptured aneurysm of the anterior circulation was larger than 4 mm; (2) all were examined by high resolution plain and enhanced scanning MRI and magnetic resonant angiography (MRA) images; and (3) all images showed the exterior and interior of the aneurysm lumen clearly.

The exclusion criteria were as follows: (1) secondary intracranial aneurysms, such as traumatic aneurysms and infectious aneurysms; and (2) intracranial aneurysms complicated with other cerebrovascular malformations.

Patients were evaluated for the following clinical indicators: sex, age, history of type 2 diabetes mellitus, smoking, hypertension, and family history.

Aneurysms were evaluated for the following morphological indicators: size; neck diameter; size ratio; aspect ratio; whether the aneurysm was at the vessel bifurcation point; whether there was thrombosis; the distribution and signal of any thrombus within the aneurysms; and whether the aneurysm wall was enhanced. Symptoms including headaches and oculomotor nerve paralysis without obvious inducement, and their associated cerebral location symptoms were excluded.

Scanning Method

Patients were scanned with the GE Signa HDX 3.0 T MRI scanner with an 8-channeled head coil at Tongguan Hospital, or the Philips Ingenia 3.0T MRI scanner with a digital channel coil at Gaoxin Hospital, Lianyungang, China.

Patients were required to keep their head still during scanning. Three-dimensional time of flight magnetic resonance imaging (MRA) images; and (3) all images showed the exterior and interior of the aneurysm lumen clearly.

**Scanning Method**

Patients were scanned with the GE Signa HDX 3.0 T MRI scanner with an 8-channeled head coil at Tongguan Hospital, or the Philips Ingenia 3.0T MRI scanner with a digital channel coil at Gaoxin Hospital, Lianyungang, China.
angiography (3D-TOF-MRA) was performed on all patients, with a slice thickness of 1 mm. The 3D-TOF-MRA was used first to locate and determine the longitudinal axis of the aneurysms. Transverse scans were performed, followed by sagittal scanning, as required. The fat suppression technique was used in T1 and T2 scanning sequences according to the following parameters.

GE HR-MRI sequences: (1) SE T1; Mode 2D; TR/TE 700 ms/min full; FOV 24; phase FOV 0.75; NEX 3; slice thickness 1.2 mm; and matrix 256×256; (2) OX T2FSE; mode 2D; TR/TE 4480 ms/min full, FOV 24, phase FOV 0.75, NEX 4, slice thickness 1.2 mm; and matrix 256×256.

Philips HR-MRI sequences: (1) T1WI VISTA; TR/TE 800 ms/70 ms; FOV 160 mm×160 mm; slice thickness 1 mm; and matrix 272×272; (2) T2WI VISTA; TR/TE 1800 ms/236 ms; FOV 160 mm×160 mm; slice thickness 1 mm; and matrix 276×271.

Following the plain scan above, patients were injected with 10% gadolinium-DTPA for enhanced scanning with the same parameters. Patients were injected intravenously with 0.2 mL/kg of gadolinium-DTPA via the median cubital vein with a flow rate of 1.5-3 mL/s. Enhanced scans were performed 5 min after injection.

**Image Qualification**

Image quality was graded according to the following 5-point Likert scale [11], and images with scores ≤3 were excluded: (a) 5 points: very clear image without artifacts; clear and distinguishable lumen, wall boundary, and wall periphery; (b) 4 points: clear image with few artifacts; clear and distinguishable lumen, wall boundary, and wall periphery; (c) 3 points: generally clear image with artificial interference; less clear lumen, wall boundary and wall periphery; (d) 2 points: poor image with more artifacts; distinguishable lumen and wall boundary, as well as fuzzy wall periphery; and (e) 1 point: very poor image with fuzzy lumen, wall boundary and wall periphery.

**Definition of Aneurysm Indicators**

The definitions of aneurysm indicators were as follows: (a) **Aneurysm neck**: the line between 2 points where the aneurysm and parent artery intersect. (b) **Aneurysm height**: the line between the highest point of the aneurysm and the midpoint of the neck of the aneurysm. (c) **Aneurysm size**: the largest value between the maximum width and height of the aneurysm. The maximum width of an aneurysm is defined as the length of the maximum segment that is perpendicular to the aneurysm height, and connects the bilateral walls of the aneurysm. (d) **Aspect ratio**: aneurysm height/aneurysm neck. (e) **Size ratio**: aneurysm height/parent artery diameter. (f) **Diameter of parent artery**: the average diameter of all vessels associated with the aneurysm calculated with the formula (C1+C2-C1-C2)/n, where C is the diameter of each vessel and n is the number of vessels [12].

**Thrombus distribution**: determined from transverse view of T1 enhanced images. Aneurysms were divided into 4 quadrants (left, right, dorsal and ventral) by 2 intersecting lines at the center of the aneurysm (**Figure 1**). If the distribution of thrombi involved several quadrants, the quadrants with the densest collection of thrombi shall be taken as the location of the thrombi within that aneurysm cavity.

Each aneurysm image was evaluated by 2 neuroimaging specialists with 13 and 25 years of experience using the GE adw 4.5 post-processing workstation, respectively. All the measurements were made on the virtual reality image of the 3D-TOF-MRA, and the initial reconstructed virtual reality image was increased in window width until the aneurysm was visualized to the greatest extent possible (**Figure 2**). Their combined average scores for all parameters were used as the final result.

**Statistical Analysis**

SPSS 16.0 software was used for data analysis. All aneurysm images were divided into thrombus and non-thrombus groups. The measurement data demonstrated normal distribution and were expressed as median and standard deviation. The independent t test was employed for comparisons between 2 groups. The count data were described by case number, such as hypertension history, smoking history, and other indicators. Differences between the 2 groups were compared by the chi-squared test with an R×C table. Univariate analyses were first used to select variables with statistical significance between the 2 groups of aneurysms, followed by multivariate logistic regression analysis with forward stepwise variable selection, with alpha = 0.05 as the test level. P<0.05 was set as the statistically significant threshold. The odds ratio (OR) and 95% confidence interval (CI) were calculated, and finally receiver operating characteristic (ROC) curve analysis was performed.

**Results**

**HR-MRI Features of Thrombotic Intracranial Aneurysms**

HR-MRI images from 152 patients with 152 unruptured intracranial aneurysms were initially selected for analysis. However, 16 images (14 GE 2D and 2 Philips 3D images) contained artifacts and received Likert scores of 3, and thus, did not meet the diagnostic requirements. A final total of 136 patients with 136 unruptured anterior circulation aneurysms (47 GE 2D images and 89 Philips 3D images) were included in this study. The patients consisted of 72 women and 64 men, with an average age of 62±11 years (range 29 to 89 years).
Patients were divided into 2 groups, with and without thrombus. The thrombus group contained 41 aneurysms from various locations: 3 anterior cerebral artery, 8 anterior communicating artery, 11 middle cerebral artery, 12 internal carotid artery, and 7 of posterior communicating artery origin. The non-thrombus group, with 95 aneurysms, included 7 anterior cerebral artery, 16 anterior communicating artery, 28 middle cerebral artery, 26 internal carotid artery, and 18 in the posterior communicating artery. The characteristics of the aneurysms in the 2 groups are shown in Table 1.

Single factor analysis showed that differences in the patient characteristics of sex, age, and hyperlipidemia and aneurysm characteristics of size, neck diameter, aspect ratio, and size ratio...
between the 2 groups were statistically significant (P<0.05). Multi-factor regression analysis of these meaningful variables showed that aneurysm size (OR=2.180, 95% CI: 1.332-3.570) and aspect ratio value (OR=7.495, 95% CI: 1.034-54.346) were significantly associated with TIA formation (Table 2). In addition, aneurysm size and aspect ratio value were analyzed by an ROC curve. For aneurysms larger than 8 mm, the sensitivity and specificity of thrombosis prediction were 83% and 93%, respectively, with an area under the curve of 0.962. When aspect ratio values were higher than 2.5, the sensitivity and

Figure 2. A thrombotic aneurysm on the posterior communicating artery of the right internal carotid artery of a 51-year-old man. (A) Initial reconstructed virtual reality image of 3-dimensional time of flight magnetic resonance angiography (3D-TOF-MRA) showing a right internal carotid artery posterior communicating initiating aneurysm, but not maximal visualization of the aneurysm. (B) On the basis of Figure A, the virtual reality image with a larger window width showing the aneurysm to the greatest extent, and displaying the rough and uneven shape of aneurysm with a size of 2.1 cm and aspect ratio value of 2.9. Line (a) represents the aneurysm neck; line (b) represents the height of the aneurysm; line (c) represents the width of the aneurysm; (d1) and (d2) represent the diameter of the aneurysm parent artery related to the aneurysm; that is, the largest parent within 5 mm from the proximal aneurysm neck. (C) Sagittal T2WI image from the GE 2D HR-MRI scanner showing the uneven hypointense thrombus spreading from the aneurysm body to the neck. (D) Enlarged view of (B) showing the morphology and distribution of the thrombus within the aneurysm neck. All images were analyzed by GE adw 4.5 post-processing workstation.
Specificity of thrombosis prediction reached 75% and 95%, respectively, with an area under the curve of 0.948. Compared with the AWE in the non-thrombus group, the proportion of AWE in the thrombus group was significantly higher. The proportion of patients with clinical symptoms was also significantly higher in the thrombus group (Table 3).

TIA were divided into symptomatic and asymptomatic groups (symptoms included headaches and oculomotor nerve paralysis without obvious induction, while their associated cerebral location symptoms were excluded). The thrombi distribution and AWE analyses for the 2 groups are shown in Table 4. Among the 41 TIA, 6 aneurysms had thrombi in the neck (Figure 2). For the remaining cases, the thrombi mostly occurred in the body of the aneurysm, with more distributed in the dorsal quadrant. However, there was no statistically significant difference between the 2 groups. In addition, 5 AWE analyses were performed: no enhancement, spot enhancement, diffused enhancement, thrombus surface enhancement, and thrombus diffuse enhancement, but no significant differences was observed between the 2 groups.

### Table 1. Characteristics of patients in the 2 groups, with and without intra-aneurysm thrombosis.

| Characteristics | Thrombosis group (n=95) | Non-thrombus group (n=41) | Total (n=136) | P value |
|-----------------|-------------------------|---------------------------|----------------|---------|
| Sex             |                         |                           |                | 0.018   |
| Female, n (%)   | 44 (46.3)               | 28 (68.3)                 | 72 (52.9)      |         |
| Male, n (%)     | 51 (53.7)               | 13 (31.7)                 | 64 (47.1)      |         |
| Age, y, mean±SD | 63±10                   | 61±10                     |                |         |
| Aneurysm size, mm, mean±SD | 6.1±1.0       | 13.6±6.1                  | 8.4±4.9       | <0.001  |
| Aneurysm neck, mm, mean±SD | 3.3±0.6        | 3.9±0.7                   | 3.4±0.7       | <0.001  |
| Aspect ratio, mean±SD | 1.9±0.2          | 3.4±1.1                   | 2.4±1.0       | <0.001  |
| Size ratio, mean±SD | 2.4±0.7          | 3.9±1.0                   | 2.9±1.1       | <0.001  |
| Shape           |                        |                           |                | 0.455   |
| Regular, n (%)  | 49 (51.6)               | 24 (58.5)                 | 73 (53.7)      |         |
| Irregular, n (%)| 46 (48.4)               | 17 (41.5)                 | 63 (46.3)      |         |
| Location        |                        |                           |                | 0.991   |
| Anterior cerebral artery, n (%) | 7 (7.4)           | 3 (7.3)                   | 10 (7.4)       |         |
| Anterior communicating artery, n (%) | 16 (16.8)       | 8 (19.5)                  | 24 (17.6)      |         |
| Middle cerebral artery, n (%) | 28 (29.5)        | 11 (26.8)                 | 39 (28.7)      |         |
| Internal carotid artery, n (%) | 26 (27.4)        | 12 (29.3)                 | 38 (27.9)      |         |
| Posterior communicating artery origin, n (%) | 18 (18.9)       | 7 (17.1)                  | 25 (18.4)      |         |
| Artery bifurcation, n (%) | 39 (41.1)        | 20 (48.8)                 | 59 (43.4)      | 0.404   |
| Type 2 diabetes mellitus, n (%) | 41 (43.2)       | 17 (41.5)                 | 58 (42.6)      | 0.855   |
| History of smoking, n (%) | 44 (46.3)       | 21 (51.2)                 | 65 (47.8)      | 0.599   |
| Hypertension, n (%) | 51 (53.7)       | 19 (46.3)                 | 70 (51.5)      | 0.482   |
| Hyperlipidemia, n (%) | 51 (53.7)       | 19 (46.3)                 | 70 (51.5)      | 0.482   |
| Family history, n (%) | 28 (29.5)       | 9 (22.0)                  | 37 (27.2)      | 0.366   |

SD – standard deviation.

### Table 2. Multivariate regression analysis of thrombosis factors in aneurysm.

| Variables                | B     | OR    | 95% CI     | P value |
|--------------------------|-------|-------|------------|---------|
| Aneurysm size            | 0.779 | 2.180 | 1.332-3.570| 0.002   |
| Aspect ratio             | 2.014 | 7.495 | 1.034-54.346| 0.046   |

B – partial correlation coefficients; OR – odds ratio; CI – confidence interval.
Treatment of Patients with TIA

Among the 41 patients with TIA, 9 asymptomatic patients did not undergo surgical or specialized treatment, but CTA was performed to determine whether changes were presented within the aneurysms. Among the 32 patients who were symptomatic, 6 patients and their family members refused surgical treatment due to the patients’ advanced age, and instead these patients were given conservative symptomatic treatments with CTA follow-up. For the remaining 26 symptomatic patients, 4 underwent interventional embolization and 12 underwent conventional craniotomy. Seven patients with giant TIA without thrombus involving the aneurysm neck underwent thrombectomy followed by craniotomy. For the 4 patients with aneurysm neck involvement, 1 aneurysm neck was clamped with a straight clip combined with a cross-vessel clip; 2 were treated by thrombectomy; and 1 patient underwent aneurysm isolation and revascularization.

No death occurred in the 26 operated patients, and CTA follow-up at 2 months showed no aneurysm development. Thereafter, 24 patients remained symptom-free, while 2 patients had incomplete hemiplegia.

Table 3. Comparison of aneurysm wall enhancement and clinical symptoms between the 2 groups, with and without thrombosis.

| Characteristics | Non-thrombosis group (n=95) | Thrombosis group (n=41) | Total (n=136) | P value |
|-----------------|------------------------------|-------------------------|---------------|---------|
| AWE            |                              |                          |               | 0.023   |
| With, n (%)    | 28 (29.5)                    | 4 (9.8)                 | 32 (23.5)     |         |
| Without, n (%) | 67 (70.5)                    | 37 (90.2)               | 104 (76.5)    |         |
| Related symptoms |                              |                          |               | 0.040   |
| With, n (%)    | 56 (58.9)                    | 32 (78.0)               | 88 (64.7)     |         |
| Without, n (%) | 39 (41.1)                    | 9 (22.0)                | 48 (35.3)     |         |

AWE – aneurysm wall enhancement.

Table 4. Comparison of high-resolution magnetic resonance imaging characteristics of thrombotic intracranial aneurysm between the 2 groups, with and without symptoms.

| Characteristics | Symptomatic group (n=32) | Asymptomatic group (n=9) | Total (n=41) | P value |
|-----------------|--------------------------|--------------------------|---------------|---------|
| Thrombus site   |                          |                          |               | 0.845   |
| Aneurysm body, n (%) | 28 (87.5) | 7 (77.8) | 35 (85.4) |         |
| Aneurysm neck, n (%)    | 4 (12.5) | 2 (22.2) | 6 (14.6) |         |
| Thrombus attachment site side |                  |                          |               | 0.982   |
| Left, n (%)     | 5 (15.6)                  | 1 (11.1)                 | 6 (14.6)      |         |
| Right, n (%)    | 9 (28.1)                  | 3 (33.3)                 | 12 (29.3)     |         |
| Ventral, n (%)  | 7 (21.9)                  | 2 (22.2)                 | 9 (22.0)      |         |
| Dorsal, n (%)   | 11 (34.4)                 | 3 (33.3)                 | 14 (34.1)     |         |
| Enhancement type |                          |                          |               | 0.124   |
| No enhancement, n (%) | 1 (3.1) | 3 (33.3) | 4 (9.8) |         |
| Wall with punctate enhancement, n (%) | 18 (56.3) | 1 (11.1) | 19 (46.3) |         |
| Wall with diffuse enhancement, n (%) | 13 (40.6) | 5 (55.6) | 18 (43.9) |         |
| Thrombus with surface enhancement, n (%) | 11 (34.4) | 2 (22.2) | 13 (31.7) |         |
| Thrombus with diffuse enhancement, n (%) | 21 (65.6) | 7 (77.8) | 28 (68.3) |         |
Discussion

Treatment of TIA needs to achieve 2 outcomes: removing the lesions to reclaim the cerebral space while preventing rupture of the aneurysm and maintaining the integrity of the patient’s artery and avoid cerebral ischemia. Hence, a number of issues should be clarified before surgery.

First, because the size of a TIA is generally large, it is often necessary to temporarily block the internal carotid artery before surgery. This not only reduces intraoperative blood loss but also reduces the aneurysm volume, allowing the boundary of the aneurysm to separate from surrounding tissues to better expose the aneurysm neck. The volumes of common aneurysms are often significantly reduced after these temporary occlusion treatments. However, for giant TIA, the reduction in aneurysm volume is limited by the presence of the thrombus within the aneurysm cavity.

Second, for aneurysms with a thrombus involving the aneurysm neck, it is necessary to determine whether the proximal end of the thrombus exceeds the connecting line of the aneurysm neck and herniates into the parent artery cavity. If the thrombus does not cross the aneurysm neck, clipping of the aneurysm is the routine procedure. If the thrombus herniates into the parent artery cavity when routine clipping is carried out, the thrombus can be fragmented and enter the parent artery to embolize the branching vessels of the parent artery, resulting in acute cerebral infarction. In these cases, it is necessary to choose other more sophisticated surgical methods, such as aneurysm isolation. Thus, the distribution and range of the thrombus in the aneurysm neck should be determined before surgery to allow surgeons to choose the correct aneurysm clip and clipping direction. When the thrombus attached to the medial wall of the aneurysm neck is less than half of the circumference of the neck, a cross-vessel clamp is needed to clip the aneurysm neck wall. However, if the thrombus is more than half of the aneurysm neck circumference, it is difficult to perform clipping since this can result in incomplete clipping or laceration of the tumor neck. In this case, interventional embolization or other surgical procedures should be chosen.

Third, for patients with calcified plaques on the aneurysm neck, clipping procedures can lead to incomplete clipping or avulsion of the aneurysm neck, resulting in massive hemorrhage and even the death of the patient. If there is no appropriate examination method to identify the distribution and range of the thrombus in the aneurysm before surgery, preoperative planning and surgical technique selection will be impacted, with possible severe consequences on surgical outcomes and patient survival. As such, an accurate examination method is needed to display the true diameter of the arteries and the distribution range of thrombi in aneurysm cavities.

HR-MRI is often used for vascular wall imaging, and has become the criterion standard for head and neck plaque imaging. Thus, HR-MRI can be used to show the degree of inflammation in the aneurysm wall, as well as the scope and location of the endovascular thrombus before surgery. In addition, HR-MRI is helpful not only to find out the localization of the brain tissues supplied by the perforating artery with the aneurysm but also to select the appropriate surgical methods and approaches to avoid postoperative cerebral ischemia. However, it is difficult to popularize the use of HR-MRI as a routine examination method for intracranial aneurysms because the examination time is relatively long at more than 30 min. As such, research to improve the diagnosis of TIA must build on common examination methods, such as conventional CTA or MRA images, which allow neurosurgeons to evaluate all intracranial aneurysms for surgery. For those with a likelihood of thrombosis, additional evaluation can follow with HR-MRI to identify the scope and location of the thrombi.

In this study, the analysis of a number of factors revealed an aneurysm size > 8 mm or aspect ratio >2.5 as independent factors that predicted TIA formation. The thrombus formation process is complex, with several recent reports beginning to provide insights into the possible contributing factors, including blood flow residence time, wall shear stress, and eddy currents in the blood flow. Increased blood flow residence time and low wall shear stress have been shown to promote platelet aggregation and adherence to the vascular wall [13-15]. Blood flow is characterized by laminar flow, eddy currents, and turbulence. Eddy currents are created by slower laminar flow along the vessel wall and faster flow near the center [16]. Blood flow to large aneurysms is increased, and combined with the larger cavity, it enhances the formation of eddy current, which can damage the vessel walls and increase platelet aggregation and thrombi formation [17]. The increased blood flow also leads to longer residence time within the aneurysm cavity and increased platelet aggregation. For aneurysms of the same size, a higher aspect ratio value indicates a larger aneurysm body with a smaller neck. This slows the blood flow into the aneurysm, resulting in increased retention time, blood stasis, and reduced wall shear stress, all contributing to platelet aggregation and thrombus formation [18,19]. Thus, the HR-MRI parameters determined in our study for aneurysm size (>8 mm) and aspect ratio (>2.5) may be helpful for clinicians to quickly determine whether thrombosis is present following standard CTA or MRA evaluation, thereby saving medical resources and examination time.

In this study, the proportion of AWE and clinical symptoms were significantly higher in the thrombus group. Local inflammation in the aneurysm has been shown to predispose patients to thrombosis formation [20]. Persistent inflammation can enhance aneurysm wall permeability, allowing contrasting...
agents to penetrate the wall, leading to increased AWE. In giant TIA, the slowed blood flow remains longer in the aneurysm cavity and can even temporarily stagnate, which can result in enhanced contrast agent signal [21]. Intra-aneurysm thrombus can also achieve recanalization through hemolytic mechanisms [22], resulting in neo-vasculatures communicating with blood flows of normal pressure. This often leads to spontaneous aneurysm rupture, which should not be viewed as the aneurysm self-healing, since severe cerebral hemorrhage can result. Thus, regular clinical follow-up is critical. The incidence of clinical symptoms in the thrombus group was higher than that in the non-thrombus group, which may be associated with the larger aneurysms compressing surrounding tissues [23]. Inflammation of the aneurysm wall can also contribute to clinical symptoms in patients with TIA [24].

In this study, thrombi depositions were mostly located in the dorsal quadrant of the aneurysms, and no significant difference was found between the symptomatic and asymptomatic groups. This result suggests that the location of the thrombi is not fixed and likely depends on hemodynamics, aneurysm morphology, and many other factors. Since the location of the thrombi cannot be predicted, HR-MRI should be performed for thrombotic aneurysms before surgery to clarify the specific location of thrombus and ensure surgical safety.

Several aspects of this study can be improved. First, while patients were recruited at our hospital, the MRI scans were performed on different MRI scanners in 2 hospitals. Standardizing the data collection to 1 system and location will reduce data acquisition bias. Secondly, pathological analysis of the aneurysms will provide insights into the mechanism of thrombus formation and AWE effects. Third, a hemodynamic study should be conducted to explore the relationship between hemodynamics and thrombosis.

Conclusions

Our study has shown that aneurysm size (>8 mm) and aspect ratio (>2.5) are significant predictors of TIA, and recommends additional HR-MRI evaluation to determine the specific scope of the thrombi, including distribution, location relative to aneurysm neck as well as the surrounding conditions of the parent artery. This will be helpful to the development of more accurate treatment plans and the improvement of patient prognosis.

Ethics Approval

Our study was performed with the approval of the local Medical Ethics Committee, and all the enrolled patients gave their written informed consent before the inclusion in the study.

Declaration of Figures’ Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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