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Original Article

Angiographic morphologies of wide-necked cerebral aneurysms for predicting immediate incomplete occlusion after coil embolization

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Received: 14 December 2024
Accepted: 07 February 2025
Published: 07 March 2025

DOI
10.25259/SNI_1079_2024

Quick Response Code:

ABSTRACT

Background: Wide-necked cerebral aneurysms present unique challenges in endovascular treatment, with immediate incomplete occlusion posing significant risks for recurrence and mortality. However, the predictive factors of immediate incomplete occlusion after coil embolization of wide-necked aneurysms have not been identified. Thus, this study aimed to identify specific angiographic morphologies predictive of immediate incomplete occlusion after coil or stent-assisted embolization for wide-necked aneurysms.

Methods: This retrospective case–control study evaluated all patients diagnosed with cerebral wide-necked aneurysms who underwent endovascular treatment between January 2009 and December 2019. The case was defined as wide-necked aneurysms with immediate incomplete occlusion, while control was defined as those with immediate complete occlusion. The cases and controls were compared in a 1:3 ratio. Angiographic morphologies as the predictors of immediate incomplete occlusion were analyzed using multivariable logistic regression with adjusted odds ratio (aOR) and 95% confidence interval (CI).

Results: There were 73 and 226 cases and controls, respectively. Aneurysm height ≥5.6 mm (aOR, 8.14; 95% CI, 4.21–15.75; $P < 0.001$), absent shoulder (aOR, 4.22; 95% CI, 1.74–10.25; $P = 0.001$), one-sided shoulder (aOR, 2.54; 95% CI, 1.26–5.15; $P = 0.009$), and presence of vessel incorporation (aOR, 2.2; 95% CI, 1.02–4.73; $P = 0.044$) were independent risk factors of immediate incomplete occlusion.

Conclusion: Aneurysm height ≥5.6 mm, absent two-sided shoulder, and presence of vessel incorporation significantly predict immediate incomplete occlusion after coil embolization for wide-necked aneurysms.

Keywords: Aneurysm, Angiographic, Coil embolization, Morphologies, Occlusion, Predictor, Wide-necked

INTRODUCTION

Unruptured cerebral aneurysms are prevalent in 3.2% of the population[30], and the rupture rate ranges from 2%[26] to 2.7% [22], with the risk of rebleeding is 13.6%.[24] Further, the mortality rate is as high as 65% in untreated ruptured aneurysms.[18] The mortality rate is lower in patients with cerebral aneurysms treated with coil embolization.[21,28] Immediate complete occlusion is essential for good treatment outcomes, with immediate incomplete occlusion increasing the risk of recurrence and mortality.[8,11-13,15,20,25,27] Aneurysm neck size is an important factor for

predicting successful angiographic occlusion of aneurysms with coil embolization.[10,17]

Wide-necked aneurysms, defined as those with a neck size ≥4 mm, have a significantly lower rate of initial treatment success than narrow-necked aneurysms.[10,23] Wide-necked aneurysms, also defined according to the dome-to-neck ratio and aspect ratio in addition to the neck size,[9] present a treatment challenge and have a lower complete occlusion rate than small-necked aneurysms.[6,23,25] Wide-necked aneurysms have varying angiographic morphologies, such as high aneurysm height,[29] irregular shape,[1] absent two-sided shoulder,[4] positional type (sidewall and bifurcation),[7] and vessel incorporation,[16] and these influence the occurrence of incomplete occlusion. In addition, the location of sidewall aneurysms, symmetry of bifurcation of bifurcated aneurysms, inflow angle, regional vasospasm, and rupture status can present technical difficulties, affecting occlusion outcomes in wide-necked aneurysms. However, the predictors of immediate incomplete occlusion after coil embolization of wide-necked aneurysms have not been established. Therefore, this study aimed to identify angiographic morphologies of wide-neck aneurysms that were predictive of immediate incomplete occlusion after coil- or stent-assisted embolization.

MATERIALS AND METHODS

Study design, setting, and participants

This retrospective case–control study was approved by the Institutional Review Committee of our university and was conducted according to the tenets of the Declaration of Helsinki.

This study was conducted in a main tertiary hospital. All patients diagnosed with cerebral wide-necked aneurysms and who underwent endovascular treatment between January 2009 and December 2019 were evaluated. The patients were identified using the International Classification of Disease, Tenth Revision (ICD-10) for cerebral aneurysm, aneurysm of the carotid artery, and subarachnoid hemorrhage. The patient selection flowchart is shown in Figure 1. Only those who were treated with endovascular coiling, either simple coiling or stent-assisted coiling, were eligible for this study. Wide-necked aneurysms were defined as those with neck width ≥4 mm, dome-to-neck ratio (ratio of maximum dome width to neck width) <2, or aspect ratio (ratio of maximum aneurysm height to neck width) <2.[9]

The sample size was calculated using two-proportion differences based on the prevalence of two-sided shoulders of wide-necked aneurysms. As there was no similar previous study, we estimated two proportions from the average 67% prevalence rate of absent two-sided shoulder of wide-necked aneurysm from a previous study,[4] accounting for 60% and 80% prevalence of absent two-sided shoulder in immediate complete and incomplete occlusions, respectively. Considering a 95% confidence interval (CI), 90% power, and ratio of 3 for immediate incomplete and complete occlusion, at least 71 and 213 wide-necked aneurysms with immediate incomplete and complete occlusion, respectively, were required.

Study variables

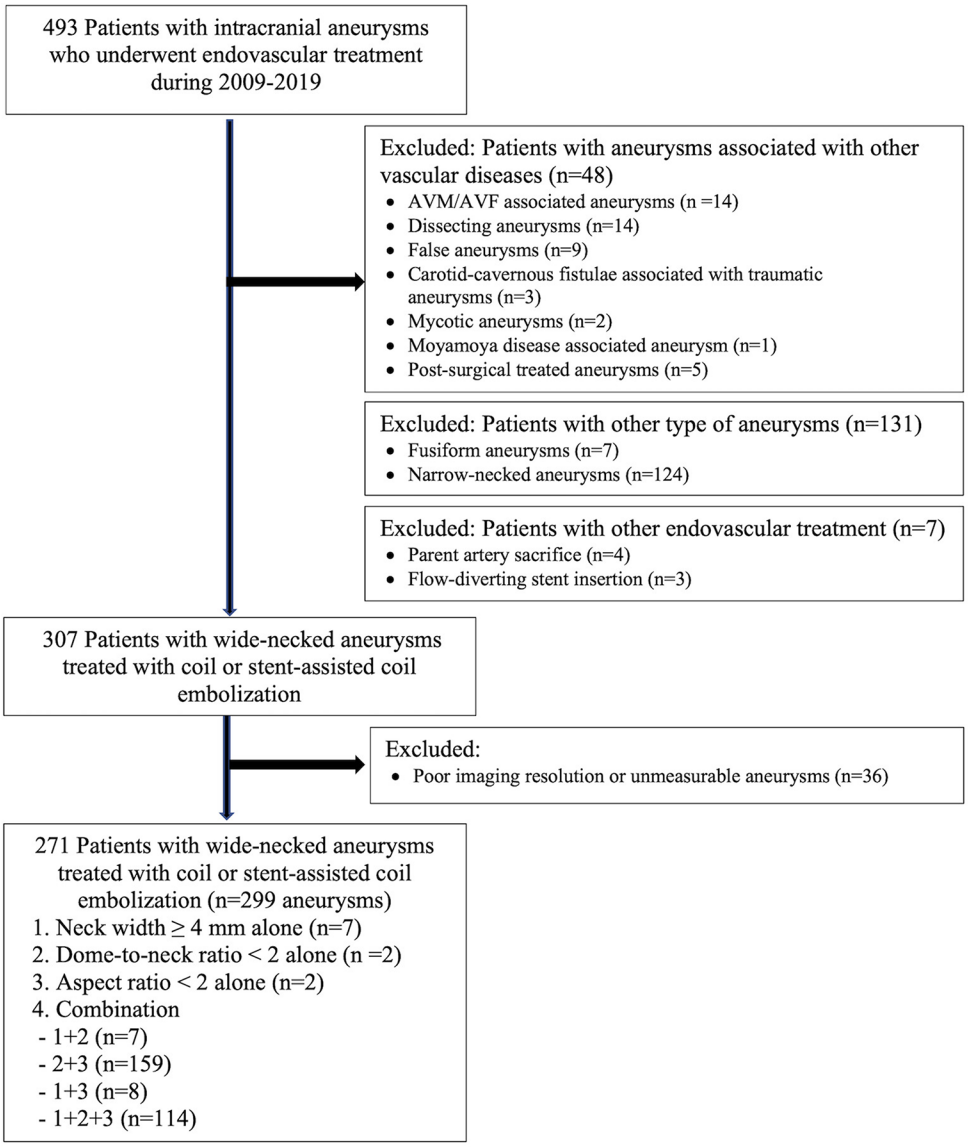
The exposures of interest were the angiographic morphology of wide-necked aneurysm related to the endovascular treatment outcomes, namely, aneurysm height, shape, shoulder, positional type (sidewall and bifurcation),[2] vessel incorporation, inflow angle,[3] and other potential factors (i.e., vasospasm, rupture status, and location, and type of endovascular treatment). These variables were reviewed from digital subtraction angiography (DSA) with three-dimensional (3D) reconstruction images at the time of endovascular treatment or within 7 days before endovascular treatment.

The primary outcome measure was the prediction of incomplete occlusion assessed immediately after coil embolization using 2D or 3D angiograms. The degree of occlusion was defined according to the modified Raymond–Ray classification (MRRC)[19] and was classified into two categories: complete occlusion and incomplete occlusion. Complete occlusion was defined as MRRC Class I, that is, no contrast filling in the aneurysm. Meanwhile, incomplete occlusion included MRRC Class II (i.e., residual neck), Class IIIa (i.e., residual aneurysm with contrast within the coil interstices), and Class IIIb (i.e., residual aneurysm with contrast along the aneurysm wall).

The wide-necked aneurysms were identified from existing data, and the images were retrieved from the Picture Archiving and Communication System. Two neuro-interventional radiologists independently assessed all aneurysm images. Inconsistent assessments that ranged from 0% to 2% were discussed until an agreement was achieved.

Coiling embolization procedures

Coil embolization was performed in the in-patient setting using a DSA (Philips Allura Xper FD20/10 or Azurion 7 B20/15, Philips, Best, the Netherlands) under general anesthesia. Matrix (Boston Scientific, Natick, MA), Axium (ev3 Inc., Plymouth, MN/Medtronic, Irvine, CA), or Target (Stryker, Fremont, CA) coils were used depending on the availability at the time of the procedure. The simple coiling technique was attempted first in all wide-necked aneurysms, especially those with a dome-to-neck ratio of >1 or with the presence of an aneurysm shoulder(s). The stent-assisted coiling method using Solitaire (ev3, Irvine, CA) or Neuroform Atlas (Boston Scientific/Target, Fremont, CA) stents were used for wide-necked aneurysms with failure of



AVM: arteriovenous malformation; AVF: arteriovenous fistula

Figure 1: Flow diagram of patient selection.

simple coil embolization, dome-to-neck ratio <1, or absence of aneurysm shoulder. The treatment aim was complete occlusion or densely packed aneurysms. Post-embolization angiographies on working projection views were routinely performed to determine the occlusion result. A team of neuro-interventionists performed each treatment procedure.

Statistical analysis

Normally distributed continuous data were presented as the mean ± standard deviation, while categorical variables were presented as frequencies with percentages. All exposures were considered as initial predictors and tested for their predictive ability for immediate incomplete occlusion. As no standard cutoff value for aneurysm height was established, we identified the optimal cut-off for aneurysm occlusion using the Youden method. Univariate analysis was used to determine the factors significantly associated with immediate incomplete occlusion. Significant variables in the univariate analysis (i.e., those with $P < 0.2$) were included in the unadjusted multivariable logistic regression model. A multivariable logistic regression with a stepwise backward method was used for identifying the independent predictors of immediate incomplete occlusion. Interactions of treatment

modality with final significant predictors were also tested. The discriminating ability of the model was evaluated according to the goodness of fit with area under the curve (AUC). All statistical analyses were performed using R software version 4.3.1 (The R Foundation for Statistical Computing, Vienna, Austria). $P < 0.05$ was considered significant.

RESULTS

Among the 493 patients with intracranial aneurysms who underwent endovascular treatment during the 10-year study period, 307 patients had wide-necked aneurysms treated with coil or stent-assisted coil embolization. Of them, 36 patients who had poor imaging resolution or unmeasurable aneurysms were excluded from the study. Finally, 271 patients (average age, 62.5 ± 13.2 years; females, 71.6%) were evaluated. A total of 299 wide-necked aneurysms treated with coil embolization or stent-assisted coil embolization were analyzed. The characteristics of the wide-necked aneurysms are described in Table 1. The average height was 5.1 ± 3 mm. There were 219 ruptured aneurysms (73.2%). Most aneurysms were found at the anterior circulation (75.9%), and the most common location was at the posterior communicating artery (29.8%). Endovascular treatment with simple coiling was performed in 233 aneurysms (77.9%). The commonest degree of immediate occlusion was MRRC Class I (n = 226, 75.6%), followed by Class II (n = 37, 12.4%), Class IIIa (n = 22, 7.43%), and Class IIIb (n = 14, 4.7%).

The optimal cutoff point of maximum height for predicting immediate incomplete occlusion was 5.6 mm, with a sensitivity of 65.7% and a specificity of 78.3%. The distributions of predictors and immediate endovascular treatment outcomes are presented in Table 2. The rate of immediate incomplete occlusion was significantly higher in wide-necked aneurysms with maximal height ≥5.6 mm, irregular shape, absent two-sided shoulder, and asymmetric bifurcation or vessel incorporation. The distribution of sidewall versus bifurcation, appearance of sidewall, inflow angle, regional vasospasm, rupture status, location, and treatment modality was not significantly different between the immediate incomplete occlusion and complete occlusion groups.

Three independent factors predictive of immediate incomplete occlusion were identified in the final multivariable logistic regression model; these were maximum height, shoulder, and parent vessel incorporation [Table 3]. Aneurysm height ≥ 5.6 mm (odds ratio [OR], 8.14; 95% CI, 4.21–15.75; $P < 0.001$), absent shoulder (OR, 4.22; 95% CI, 1.74–10.25; $P = 0.001$), one-sided shoulder (OR, 2.54; 95% CI, 1.26–5.15; $P = 0.009$), and presence of vessel incorporation (OR, 2.2; 95% CI, 1.02–4.73; $P = 0.044$) significantly predicted immediate incomplete occlusion. There were no interactions of treatment modalities with final significant predictors. The receiver operating characteristic curve demonstrated an acceptable performance of these predictive factors, with an AUC of 0.799.

Table 1: Characteristics of wide-necked aneurysms (n=299).

Characteristics	Value
Maximum height	5.1 [3]
Neck width	4.1 [2.1]
Dome-to-neck ratio	1.3 [0.4]
Aspect ratio	1.3 [0.4]
Rupture status	
Ruptured	219 (73.2)
Unruptured	80 (26.8)
Location	
ACoA	53 (17.7)
PCoA	89 (29.8)
ICA	48 (16.1)
ACA	17 (5.7)
MCA	20 (6.7)
BA trunk	7 (2.3)
Tip of BA	30 (10)
VA	10 (3.3)
Others*	25 (8.3)
Anterior circulation	227 (75.9)
Posterior circulation	72 (24.1)
Type of endovascular treatment	
Simple coiling	233 (77.9)
Stent-assisted coiling	66 (22.1)
Immediate posttreatment MRRC class	
Class I	226 (75.6)
Class II	37 (12.4)
Class IIIa	22 (7.4)
Class IIIb	14 (4.7)

Data are presented as the mean [SD] or n (%). *Other including posterior cerebral artery, posterior inferior cerebellar artery, superior cerebellar artery, and anterior inferior cerebellar artery. ACA: Anterior cerebral artery, ACoA: Anterior communicating artery, BA: Basilar artery, ICA: Internal carotid artery, MCA: Middle cerebral artery, MRRC: Modified Raymond–Roy Classification, PCoA: Posterior communicating artery, SD: Standard deviation, VA: Vertebral artery

DISCUSSION

The predictors of immediate incomplete occlusion after coil embolization of wide-necked aneurysms have not been clarified to date. The present study shows that angiographic morphologies of wide-necked aneurysms are internally valid in predicting immediate incomplete occlusion after coil or stent-assisted embolization. The model that included aneurysm height ≥5.6 mm, absent two-sided shoulder,

Table 2: Distribution of predictive factors by immediate endovascular outcomes in wide-necked aneurysms (*n*=299).

	Immediate incomplete occlusion	Immediate complete occlusion	*P*-value
n (%)	73 (24.4)	226 (75.6)	
Maximum height			<0.001
<5.6 mm	25 (34.2)	177 (78.3)	
≥5.6 mm	48 (65.8)	49 (21.7)	
Shape			0.02
Simple lobe	16 (21.9)	85 (37.6)	
Irregular shape	57 (78.1)	141 (62.4)	
Shoulder			0.007
Absent	18 (24.7)	32 (14.2)	
One sided	29 (39.7)	67 (29.6)	
Two sided	26 (35.6)	127 (56.2)	
Positional type			0.334
Sidewall	47 (64.4)	129 (57.1)	
Bifurcation	26 (35.6)	97 (42.9)	
Appearance of sidewall			0.386
No	26 (35.6)	97 (42.9)	
Inner	4 (5.5)	21 (9.3)	
Outer	40 (54.8)	100 (44.2)	
Medial/lateral wall	3 (4.1)	8 (3.5)	
Appearance of bifurcation			0.002
No	47 (64.4)	129 (57.1)	
Asymmetrical	14 (19.2)	19 (8.4)	
Symmetrical	12 (16.4)	78 (34.5)	
Vessel incorporation			<0.001
Absent	49 (67.1)	204 (90.3)	
Present	24 (32.9)	22 (9.7)	
Inflow angle (degree)	124.2 [25.9]	125.4 [28.8]	0.751
Regional vasospasm			1
Absent	40 (54.8)	123 (54.4)	
Present	33 (45.2)	103 (45.6)	
Rupture status	51 (23.2)	169 (76.8)	0.549
Unruptured	22 (30.1)	58 (25.7)	
Ruptured	51 (69.9)	168 (74.3)	
Location group			1
Anterior location*	55 (75.3)	172 (76.1)	
Posterior location**	18 (24.7)	54 (23.9)	
Treatment modalities			0.272
Simple coiling	53 (72.6)	180 (79.6)	
Stent-assisted coil	20 (27.4)	46 (20.4)	

Data are presented as the mean [SD] or n (%). *Anterior circulation: Anterior cerebral artery, posterior communicating artery, internal carotid artery, anterior communicating artery, and middle cerebral artery. **Posterior circulation: Tip of basilar artery, basilar artery trunk, vertebral artery, anterior inferior cerebellar artery, posterior inferior cerebellar artery, superior cerebellar artery, and posterior cerebellar artery

and presence of vessel incorporation demonstrated robust performance, supporting its usefulness for predicting treatment outcomes. The study findings can be useful for guiding treatment techniques and devices, determining the need for further treatment, and preparing the appropriate posttreatment follow-up plan.

Table 3: Multivariate analysis of predictive factors of immediate endovascular outcomes in wide-necked aneurysms.

	Immediate complete occlusion *n* (%)	Immediate incomplete occlusion *n* (%)	Crude OR (95%CI)	*P*	Adjusted OR (95% CI)	*P* (Wald's test)	*P* (LR-test)
Maximum height							
<5.6 mm	177 (78.3)	25 (34.2)	Reference		Reference		<0.001
≥5.6 mm	49 (21.7)	48 (65.8)	6.94 (3.89–12.36)	<0.001	8.14 (4.21–15.75)	<0.001	
Shoulder							
Two sided	128 (56.4)	26 (35.6)	Reference		Reference		0.002
One sided	67 (29.5)	29 (39.7)	2.11 (1.15–3.88)	0.016	2.54 (1.26–5.15)	0.009	
Absent	32 (14.1)	18 (24.7)	2.75 (1.34–5.62)	0.006	4.22 (1.74–10.25)	0.001	
Vessel incorporation							
Absent	205 (90.3)	49 (67.1)	Reference		Reference		0.046
Present	22 (9.7)	24 (32.9)	4.54 (2.35–8.76)	<0.001	2.2 (1.02–4.73)	0.044	

CI: Confidence interval, OR: Odds ratio

To our knowledge, our study is the first to determine the predictors of immediate incomplete occlusion after coil or stent-assisted embolization in wide-necked aneurysms. We found two earlier studies assessing factors associated with immediate incomplete occlusion in cerebral aneurysms, but they were not specific to wide-necked type aneurysms.[5,17] Another study concentrated on wide-necked aneurysms but used a different outcome measure.[4] The study conducted by Kole *et al*. identified catheter stability, aneurysm neck diameter, and aneurysm geometry as significant factors.[17] Another study by Feng *et al*. found that parent artery stenosis ≥50% and aneurysm lobulation were significant contributors.[5] In addition, Decharin *et al*. highlighted angiographic morphologies of neck width <3.6 mm and the presence of a two-sided shoulder as significant predictors.[4] However, it is important to note that the simple coil embolization technique was exclusively employed in the latter study, and predictors for immediate aneurysm occlusion grade were not investigated.

Our findings on the impact of aneurysm height ≥5.6 mm on immediate incomplete occlusion align with that of a previous study that reported lower occlusion rates in wide-necked aneurysms measuring ≥10 mm than in smaller-sized wide-necked aneurysms, although each aneurysm was densely packed.[29] This association can be attributed to the challenges of positioning coils within the aneurysm sac without protruding into the parent artery, particularly in the context of large-sized, wide-necked aneurysms. Although stent-assisted techniques aim to mitigate this challenge, achieving precise control over coil distribution within a large aneurysm sac remains a complex task. In some instances, unequally dense coil loops either hinder the accessibility of deep residual spaces or create shallow spaces at the neck, leading to incomplete occlusion.

We found that the lack of a two-sided shoulder, manifesting as either an absent shoulder or a one-sided shoulder, was a significant predictor of immediate incomplete occlusion in wide-necked aneurysms. The presence of a two-sided shoulder was a significant factor in the successful application of simple coil embolization in a previous study.[4] However, its association with immediate incomplete occlusion was not investigated. We agree with their explanation that the shoulder was an important structure in supporting coil mesh and preventing coil protrusion into the parent artery, emphasizing its role in achieving aneurysm occlusion. As the presence of a two-sided shoulder enhances coil stability within the aneurysm sac, it is unsurprising that the multivariate analysis revealed that a wide-necked aneurysm with an absent or one-sided shoulder had a more significant risk of immediate incomplete occlusion than those with a two-sided shoulder.

The presence of vessel incorporation by the neck of a wide-necked aneurysm was associated with a significantly higher risk of immediate incomplete occlusion in the present study. This could be explained through the challenge of avoiding the occlusion of the incorporated branch artery during coil embolization of such an aneurysm. Although utilizing stent-assisted techniques enhances the likelihood of successful coil embolization and achieving more comprehensive packing in this context,[16] the majority of aneurysms with vessel incorporation still exhibit either near-complete occlusion or a residual portion at the neck.[14] In addition, wide-necked aneurysms featuring vessel incorporation often lead to an asymmetrical neck shape, potentially resulting in a residual space on the opposite side of the aneurysm neck from the point of origin of the incorporated vessel.

The shape of the aneurysm, aneurysm angle, location at the side wall or bifurcation, symmetric and asymmetric

bifurcation, and treatment modalities were not significantly associated with immediate incomplete occlusion in our study. A previous study showed that an irregular shape increased the risk of immediate incomplete occlusion after treatment; however, the study used the Woven EndoBridge (WEB) device, for which the selection of an appropriate device size depended on the wall and neck of an aneurysm, increasing the risk of incomplete occlusion.[1] In contrast, an irregular shape had an insignificant association with the occurrence of immediate incomplete occlusion in the current study. This may be because the coils were more effective than the WEB device in filling irregular spaces within the aneurysm sac.

The effect of aneurysm angle, location at sidewall or bifurcation, or symmetric and asymmetric bifurcation on occlusion could not be supported in our study and had not also been reported previously, thus requiring further investigation. Simple coil embolization and stent-assisted coil embolization were used to treat wide-necked aneurysms in the present study. In all aneurysms, the first-line treatment was simple coil embolization. Stent assistance was performed only when the first coil could not be framed or stabilized within the aneurysm sac. Therefore, the rates of successful treatment of a wide-neck aneurysm could not be compared between these two modalities.

To our best knowledge, no study has specifically highlighted the effectiveness of predictors for coil embolization in wide-necked aneurysms, particularly in accurately discerning between immediate complete and incomplete occlusion. Our model demonstrated strong performance, affirming its usefulness in predicting immediate incomplete occlusion. However, this study also had some limitations. First, this was a retrospective study. The identification of the patients using the ICD-10 diagnosis codes from the hospital recording system may have caused over- or underestimation of the cases; however, this was minimized as the interventions were required, and all case diagnoses were reviewed. Second, we used the neck width of ≥4 mm, the dome-to-neck ratio of <2, or the aspect ratio of <2 to define wide-necked aneurysms, as no standard definitions have been established to date. Third, the occlusion outcome may depend on the experiences of neuro-interventionists and a team of neuro-interventionists performed all procedures in our study. The results of occlusion may be different from those of other studies. Fourth, as the angiographic morphologies of wide-necked aneurysms were identified based on available projection views in the imaging studies, certain morphologies may not have been adequately captured, affecting the accuracy of identification. However, efforts were made to minimize this limitation by achieving consensus among the reviewers. Finally, the findings may have limited generalizability due to the retrospective and single-center design; however, the morphologies of wide-necked aneurysms in our study were not obviously different from those in previous studies. Further research is warranted to examine treatment outcomes in the high-risk group and to conduct long-term follow-up after treatment.

CONCLUSION

The angiographic morphologies of wide-necked aneurysms accurately predict immediate incomplete occlusion after coil- or stent-assisted embolization. The model that includes aneurysm height ≥5.6 mm, absence of two-sided shoulders, and presence of vessel incorporation demonstrated strong performance, confirming its usefulness in predicting treatment outcomes. Wide-necked aneurysms with these characteristics should be approached with caution during endovascular treatment, and alternative techniques and devices should be explored to minimize the risk of immediate incomplete occlusion.

Ethical approval: The research/study approved by the Institutional Review Board at Human Research Ethics Committee Faculty of Medicine, Prince of Songkla University, number REC.67-075-7-1, dated February 5, 2024.
Declaration of patient consent: Patient's consent was not required as there are no patients in this study.
Financial support and sponsorship: Nil.
Conflicts of interest: There are no conflicts of interest.
Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI.

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How to cite this article: Wichaitum J, Khumtong R, Riabroi K, Liabsuetrakul T. Angiographic morphologies of wide-necked cerebral aneurysms for predicting immediate incomplete occlusion after coil embolization. Surg Neurol Int. 2025;16:81. doi: 10.25259/SNI_1079_2024