The significant impact of framing coils on long-term outcomes in endovascular coiling for intracranial aneurysms: how to select an appropriate framing coil

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OBJECTIVE The importance of a framing coil (FC)—the first coil inserted into an aneurysm during endovascular coiling, also called a lead coil or a first coil—is recognized, but its impact on long-term outcomes, including recanalization and retreatment, is not well established. The purposes of this study were to test the hypothesis that the FC is a significant factor for aneurysmal recurrence and to provide some insights on appropriate FC selection.

METHODS The authors retrospectively reviewed endovascular coiling for 280 unruptured intracranial aneurysms and gathered data on age, sex, aneurysm location, aneurysm morphology, maximal size, neck width, adjunctive techniques, recanalization, retreatment, follow-up periods, total volume packing density (VPD), volume packing density of the FC, and framing coil percentage (FCP; the percentage of FC volume in total coil volume) to clarify the associated factors for aneurysmal recurrence.

RESULTS Of 236 aneurysms included in this study, 33 (14.0%) had recanalization, and 18 (7.6%) needed retreatment during a mean follow-up period of 37.7 ± 16.1 months. In multivariate analysis, aneurysm size (odds ratio [OR] = 1.29, $p < 0.001$), FCP < 32% (OR 3.54, $p = 0.009$), and VPD < 25% (OR 2.96, $p = 0.015$) were significantly associated with recanalization, while aneurysm size (OR 1.25, $p < 0.001$) and FCP < 32% (OR 6.91, $p = 0.017$) were significant predictors of retreatment. VPD as a continuous value or VPD with any cutoff value could not predict retreatment with statistical significance in multivariate analysis.

CONCLUSIONS FCP, which is equal to the FC volume as a percentage of the total coil volume and is unaffected by the morphology of the aneurysm or the measurement error in aneurysm length, width, or height, is a novel predictor of recanalization and retreatment and is more significantly predictive of retreatment than VPD. To select FCs large enough to meet the condition of $\text{FCP} \geq 32\%$ is a potential relevant factor for better long-term outcomes. These findings support our hypothesis that the FC is a significant factor for aneurysmal recurrence.

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KEY WORDS framing coil; first coil; volume packing density; recanalization; endovascular coiling; intracranial aneurysm; vascular disorders

DURING the past three decades, the treatment strategy for unruptured and ruptured intracranial aneurysms has gradually changed from surgical clipping to endovascular coiling,^{1,15,16,22,23,36} due to several advancements in coiling devices, adjunct techniques, and diagnostic imaging modalities. However, this strategy remains controversial, because endovascular management carries a higher risk of rebleeding^{2,13,16} and recurrence,^{5,19} and because the total hospital charges per case, including

the follow-up angiograms, are relatively higher than the charges for surgical clipping.⁴ Of note, recanalization and retreatment rates are reported to be 20.8% and 10.3%, respectively, according to a meta-analysis.¹³

To overcome these shortcomings, several studies have been conducted to clarify the risk factors for aneurysmal recurrence in endovascular coiling. Currently, reported associated factors include maximal aneurysm size,^{20,22} neck width,²⁵ dome neck ratio,⁸ Raymond scale score at im-

ABBREVIATIONS AUC = area under the curve; CI = confidence interval; FC = framing coil; FCP = FC percentage; FVPD = VPD of FC; ICA = internal carotid artery; MRA = MR angiogram; OR = odds ratio; PCoA = posterior communicating artery; VPD = volume packing density.

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mediate angiography,^{12,22} other angiographic scale scores at immediate angiography,^{14,30} volume packing density (VPD),^{9,31,32} particular locations such as the posterior circulation,³⁷ partially thrombosed aneurysms,^{26,35} and ruptured aneurysms.²¹

The importance of framing coils (FCs) has been reported,^{7,10,11,17,24,28,29} but to the best of our knowledge, none of these studies have analyzed the independent impact of FCs on long-term outcomes, including retreatment and recanalization. We hypothesized that an FC is a factor relevant to aneurysmal recurrence, based on the idea that adequate FC placement results in an increased durability of the entire coil mass. The main objective of the present study was to test this hypothesis and provide some insights on how an appropriate FC should be selected.

Methods

Indication for the Treatment of Unruptured Intracranial Aneurysms

Based on the Japanese studies of the natural history of intracranial aneurysms, which included 1) Unruptured Cerebral Aneurysm Study (UCAS) Japan,¹⁸ 2) Small Unruptured intracranial Aneurysm Verification (SUAVE) study,³³ and 3) Population, Hypertension, Age, Size of aneurysm, Earlier SAH from another aneurysm, and Site of aneurysm (PHASES) score,⁶ our indications for coil embolization were as follows: 1) aneurysms ≥ 7 mm in maximal diameter; and 2) other relevant factors, including maximal diameter between 5 mm and 7 mm; patient age; irregular morphology of aneurysms; multiple aneurysms; specific locations of aneurysms such as the anterior communicating artery, internal carotid artery (ICA)-posterior communicating artery (PCoA), and posterior circulation; and history of hypertension, aneurysmal subarachnoid hemorrhage, and adult polycystic kidney disease were also taken into consideration. Based on these indications, 280 unruptured intracranial aneurysms were treated between January 2008 and July 2013; 236 were included in this study and among them, 122 aneurysms were less than 7 mm in maximal diameter. The indications for those 122 aneurysms were as follows: 101 were more than 5 mm, 63 were located at the aforementioned specific locations, 35 had irregular morphology, 25 existed in patients under the age of 50 years, 25 existed in patients over the age of 70 years, 17 had coexisting multiple aneurysms, and 5 were associated with adult polycystic kidney disease. The average age of patients with aneurysms less than 7 mm was 59.2 years (range 31–76 years).

Patient Data Collection

We retrospectively reviewed procedural and angiographic aspects of endovascular coiling for 280 unruptured intracranial aneurysms treated between January 2008 and July 2013.

First, we excluded 21 aneurysms treated with hydrogel coils, and 12 aneurysms with insufficient information on FCs or aneurysmal volume. Four aneurysms with intraoperative rupture were also excluded because intraoperative rupture makes it difficult to accurately calculate VPD and framing coil percentage (FCP) due to coils deployed out-

side of aneurysms. Finally, 7 aneurysms without follow-up angiograms or MR angiograms (MRAs) were excluded. As a result, 236 aneurysms were included for the analysis of long-term outcomes.

Procedure records, medical charts, and initial and follow-up angiograms were reviewed to obtain the following information: age; sex; aneurysm location; aneurysm morphology; maximal size, length, width, and height; neck width; dome neck ratio; estimated volume; assist techniques chosen; recanalization; retreatment; follow-up periods; and choice of FC, VPD, volume packing density of the FC (FVPD), FCP and Raymond scale score²² at the initial and follow-up angiography.

Aneurysm volume, VPD, and FVPD were calculated as follows:

Estimated aneurysm volume = $\pi \times a \times b \times c/6$, where a = length, b = width, and c = height.

VPD (%) = $100 \times (\text{total coil volume}/\text{estimated aneurysm volume})$

FVPD (%) = $100 \times (\text{FC volume}/\text{estimated aneurysm volume})$

FCP was also calculated, which was equal to the FC volume as a percentage of the total coil volume and therefore unaffected by aneurysm morphology or measurement error in aneurysm length, width, or height.

The data were used to analyze the factors associated with aneurysmal recurrence and to provide a predictive scoring system for aneurysmal recurrence based on the analysis. Informed consent was obtained from the patients who participated in this clinical investigation and the official approval was obtained from our Institutional Review Board at Toranomon Hospital.

Endovascular Procedures

Each endovascular procedure was performed at a single center (Toranomon Hospital) between January 2008 and July 2013 by, or under the supervision of, the consultant physician (Y.M.). All patients were treated under general anesthesia and intravenous heparin was administered immediately after an arterial sheath placement. A biplane angiographic unit (Allura Xper FD 20/20, Philips Medical Systems) was used for all procedures. The catheters and the FCs were selected based on the accessibility to aneurysms and the morphology, length, width, height, and maximal size of the aneurysms, without prospectively calculating FVPD. The choice of assist devices including balloons, double catheters, stents, or the combination of any of these also depended on the accessibility to aneurysms and the morphology and the size of the aneurysms, but the fundamental strategy was that a balloon catheter was almost always a standby rescue strategy for possible intraoperative rupture, and a stent-assisted technique was selected for wide-neck aneurysms more than 7 mm in diameter as a principle. The delivery of the coils into aneurysms was stopped when Raymond scale score of 1 was achieved or no additional coil could be inserted.

Outcomes and Follow-Up Evaluations

Immediate angiograms after the procedures and the follow-up angiograms at 1 year were classified using the

Raymond scale. After the 1-year follow-up, we routinely saw the patients at least every year on an outpatient basis and evaluated MRAs to detect any sign of recanalization, which prompted additional angiograms. Recanalization was defined as any worsening of angiographic obliteration. Aneurysms with recanalization were retreated if they were judged as Raymond scale Score 3, and also the residual parts of the aneurysms were large enough for multiple coils more than 2 mm in diameter to be inserted. The other recanalized aneurysms with Raymond scale Score 2 or Raymond scale Score 3 with minimum recurrence were closely observed. The entire operative team was involved in the evaluation of follow-up angiograms. Before we began this retrospective study, VPD, FVPD, and FCP had never been calculated and thus had no impact on the process of decision making regarding recanalization and retreatment.

Statistical Analysis

Either the chi-square test or Fisher's exact test was used to analyze the binary variables, and the unpaired t-test or 1-way ANOVA was used for continuous variables. Data are presented as means $\pm$ standard deviations. The odds ratios (ORs) are reported along with 95% confidence intervals (CIs). All reported p values are 2-sided and $p < 0.05$ was considered statistically significant.

Univariate analysis was used to test the covariates predictive of aneurysm recurrence. Factors associated with aneurysm recurrence in univariate analysis ($p < 0.15$) were entered into a multivariate logistic regression analysis. The correlation between FCP and VPD was analyzed using Pearson's correlation test. The area under the curve (AUC) of FCP and VPD for detecting recanalization and retreatment was calculated.

All statistical analyses were performed using SPSS (version 22.0; IBM) and EZR (Saitama Medical Center, Jichi Medical University), which is a graphical user interface for R (version 2.13.0, The R Foundation for Statistical Computing).

Results

Factors Associated With Recanalization and Retreatment

Of 236 aneurysms, 33 (14.0%) underwent recanalization and 18 (7.6%) needed retreatment during the mean follow-up period of 37.7 ± 16.1 months. On univariate analysis (Table 1), the factors related to recanalization were aneurysm size (7.2 mm vs 11.5 mm, $p < 0.001$), neck width (3.9 mm vs 6.0 mm, $p < 0.001$), FCP (38.6% vs 28.8%, $p < 0.001$), VPD (29.0% vs 25.3%, $p = 0.022$), and FVPD (11.0% vs 7.5%, $p < 0.001$), whereas aneurysm size (7.4 mm vs 12.6 mm, $p < 0.001$), neck width (4.0 mm vs 6.8 mm, $p < 0.001$), FCP (38.3% vs 24.6%, $p < 0.001$), VPD (28.7% vs 25.3%, $p = 0.104$), FVPD (10.8% vs 6.6%, $p < 0.001$), and posterior location of the aneurysm (17.9% vs 38.9%, $p = 0.056$) were related to retreatment. On multivariate analysis, we entered adequate variables ($p < 0.15$) as described in the Methods section. The results (Table 2) showed that aneurysm size (OR 1.29, 95% CI 1.13–1.46, $p < 0.001$), FCP $< 32\%$ (OR 3.54, 95% CI 1.35–9.25, $p = 0.009$), and VPD $< 25\%$ (OR 2.96, 95% CI 1.23–7.13, $p = 0.015$) were significantly associated with recanalization, while aneurysm size (OR 1.25,

95% CI 1.10–1.42, $p < 0.001$) and FCP $< 32\%$ (OR 6.91, 95% CI 1.42–33.6, $p = 0.017$) were significant predictors of retreatment. VPD as a continuous value or VPD with any cutoff value could not predict retreatment with statistical significance in multivariate analysis. FVPD could not predict recanalization or retreatment in multivariate analysis, either.

Predictive Scoring System

Based on this analysis, we propose a predictive scoring system, as shown in Table 3. One point is assigned for each of FCP $< 32\%$ and aneurysm size ≥ 7 mm (an additional 1 point is assigned for aneurysm size ≥ 10 mm) and the sum of these scores is calculated. For aneurysms with the highest risk of recurrence (Score 3: aneurysm size ≥ 10 mm and FCP $< 32\%$) the frequency of recanalization and retreatment was 48.7% and 29.0%, respectively, whereas for aneurysms with the lowest risk of recurrence (Score 0: aneurysm size < 7 mm and FCP $\geq 32\%$) the frequencies were 2.3% and 0.0%, respectively. Each difference was statistically significant compared with the intermediate risk aneurysms (Score 1 or 2: 13.7% recanalization and 7.7% retreatment; Fig. 1).

Comparison Between FCP and VPD

As predictors of aneurysm recurrence, we compared FCP with VPD to clarify the characteristics of FCP, as a novel index. FVPD was excluded from the comparison because it was not able to predict long-term outcomes with statistical significance in multivariate analysis. As shown in Fig. 2, FCP varies from 8.9% to 100%, with an average of $36.8\% \pm 14.2\%$, whereas VPD varies from 9.6% to 73.5%, with an average of $28.4\% \pm 8.5\%$. The correlation value coefficient for FCP and VPD was -0.055 ($p = 0.394$). It is clearly demonstrated in Fig. 2 that even in cases with VPD $\geq 25\%$ ($n = 147$), FCP $< 32\%$ can significantly predict recanalization (3.4% vs 16.7%, $p < 0.001$) and retreatment (1.1% vs 10.0%, $p = 0.019$).

As a continuous value (Table 4), FCP was not associated with adequate aneurysmal occlusion at immediate angiography ($p = 0.694$), but compared with VPD, could significantly predict the angiographic outcomes at the 1-year follow-up ($p < 0.001$ vs $p = 0.008$), recanalization ($p < 0.001$ vs $p = 0.022$), and retreatment ($p < 0.001$ vs $p = 0.104$). The AUC of FCP for detecting retreatment was significantly higher than that of VPD (0.785 vs 0.632, $p = 0.04$). With regards to recanalization in general, the AUC was not significantly different (0.704 vs 0.643, $p = 0.394$). To summarize, VPD was a better predictor of the immediate angiographic outcomes but FCP was superior to VPD for long-term outcomes, especially the more severe form of recurrence.

Discussion

There were 4 major findings from our study: 1) FCP, which is unaffected by the morphology of the aneurysm or the measurement error in aneurysm length, width, or height, and therefore is reproducible everywhere, is a novel predictor of recanalization and retreatment; 2) to select FCs large enough to meet the condition of FCP $\geq 32\%$ is a

TABLE 1. Univariate analysis of the factors associated with recanalization and retreatment

Variable	Recanalization		p Value	Retreatment		p Value
	No (n = 203)	Yes (n = 33)		No (n = 218)	Yes (n = 18)	
Mean age $\pm$ SD (yrs)	59.6 $\pm$ 11.2	60.5 $\pm$ 12.8	0.684	60.0 $\pm$ 11.2	56.7 $\pm$ 13.1	0.242
Females (%)	149 (73.4)	28 (84.8)	0.198	161 (73.9)	16 (88.9)	0.255
Lobulated (%)	60 (29.6)	10 (30.3)	1	68 (31.2)	2 (11.1)	0.105
Posterior location (%)	37 (18.2)	9 (27.3)	0.239	39 (17.9)	7 (38.9)	0.056
Aneurysm location (%)			0.313			0.061
ACA	28 (13.8)	5 (15.2)		31 (14.2)	2 (11.1)	
MCA	8 (3.9)	2 (6.1)		9 (4.1)	1 (5.6)	
ICA-PCoA	42 (20.7)	3 (9.1)		44 (20.2)	1 (5.6)	
Other ICA aneurysms	88 (43.3)	14 (42.4)		95 (43.6)	7 (38.9)	
BA	25 (12.3)	8 (24.2)		26 (11.9)	7 (38.9)	
Other posterior aneurysms (%)	12 (5.9)	1 (3.0)		13 (6.0)	0 (0)	
Simple technique (%)	29 (14.3)	4 (12.1)	1	32 (14.7)	1 (5.6)	0.481
Balloon-assisted technique (%)	150 (73.9)	20 (60.6)	0.143	158 (72.5)	12 (66.7)	0.592
Stent-assisted technique (%)	34 (16.7)	10 (30.3)	0.089	38 (17.4)	6 (33.3)	0.114
Maximal aneurysm size $\pm$ SD (mm)	7.2 $\pm$ 2.4	11.5 $\pm$ 5.4	<0.001	7.4 $\pm$ 2.6	12.6 $\pm$ 6.1	<0.001
Mean neck width $\pm$ SD (mm)	3.9 $\pm$ 1.5	6.0 $\pm$ 2.9	<0.001	4.0 $\pm$ 1.6	6.8 $\pm$ 3.0	<0.001
Mean dome neck ratio $\pm$ SD	1.6 $\pm$ 0.5	1.6 $\pm$ 0.5	0.935	1.6 $\pm$ 0.5	1.6 $\pm$ 0.4	0.617
Mean follow-up $\pm$ SD (mos)	36.8 $\pm$ 15.7	43.7 $\pm$ 17.4	0.026	37.1 $\pm$ 16.0	46.4 $\pm$ 15.7	0.026
Immediate angiographic outcome (%)			1			0.564
Raymond Score 1	27 (13.3)	4 (12.1)		30 (13.8)	1 (5.6)	
Raymond Score 2	58 (28.6)	10 (30.3)		61 (28.0)	7 (38.9)	
Raymond Score 3	118 (58.1)	19 (57.6)		127 (58.3)	10 (55.6)	
Mean FCP (%) $\pm$ SD	38.6 $\pm$ 13.9	28.8 $\pm$ 12.7	<0.001	38.3 $\pm$ 13.9	24.6 $\pm$ 10.5	<0.001
FCP (%) <32%	69 (34.0)	25 (75.8)	<0.001	78 (35.8)	16 (88.9)	<0.001
Mean VPD (%) $\pm$ SD	29.0 $\pm$ 8.5	25.3 $\pm$ 7.7	0.022	28.7 $\pm$ 8.5	25.3 $\pm$ 8.1	0.104
VPD (%) <25%	69 (34.0)	20 (60.6)	0.006	78 (35.8)	11 (61.1)	0.043
Mean FVPD (%) $\pm$ SD	11.0 $\pm$ 4.8	7.5 $\pm$ 4.5	<0.001	10.8 $\pm$ 4.9	6.6 $\pm$ 4.3	<0.001
FVPD (%) <8%	62 (30.5)	23 (69.7)	<0.001	70 (32.1)	15 (83.3)	<0.001

ACA = anterior cerebral artery; BA = basilar artery; MCA = middle cerebral artery.

potential relevant factor for better long-term outcomes; 3) we can clearly stratify aneurysms of high and low recurrence risk based on aneurysm size and FCP; and 4) while several papers have reported that VPD or immediate Raymond scale score are among the most predictive values for retreatment other than aneurysm size,^{9,12,22,31,32} neither of them was a significant factor in our multivariate analysis.

Factors Related to Aneurysm Recurrence

The high incidence of aneurysm recurrence is considered to be the major drawback of endovascular coiling for intracranial aneurysms. Therefore, it remains important to analyze the related factors for long-term outcomes. The

recurrence rates in this study (recanalization in 14.0% and retreatment in 7.6%) were comparable to those in other reports.^{5,19} In our series, the use of stents was paradoxically correlated with poor long-term outcomes with marginal significance in univariate analysis, but it can be estimated that the aneurysms treated with stenting had substantially wider necks and larger volumes than the others, which biased the results in our series.

Many studies have been published addressing the importance of FCs: the influence of FC orientation on intra-aneurysmal and neck region hemodynamics,^{7,17,28} how FCs are related to intraoperative rupture,^{10,11} and the stability of 0.018-inch FCs in aneurysms with a high-flow parent

TABLE 2. Multivariate analysis of recanalization and retreatment

Variable	Recanalization		Retreatment	
	OR (95% CI)	p Value	OR (95% CI)	p Value
Aneurysm size (mm)	1.29 (1.13–1.46)	<0.001	1.25 (1.10–1.42)	<0.001
FCP <32%	3.54 (1.35–9.25)	0.009	6.91 (1.42–33.6)	0.017
VPD <25%	2.96 (1.23–7.13)	0.015		

TABLE 3. Predictive scoring system for aneurysmal recurrence

Variable	Score
FCP	
≥32%	0
<32%	1
Aneurysm size (mm)	
<7	0
≥7 & <10	1
≥10	2

artery.²⁹ However, as far as we know, this is the first study in which the independent impact of FCs on the long-term outcomes, including retreatment and recanalization, was discussed. One of the possible explanations for this impact is that the solid cage of the initially deployed coil, which is usually the longest and the largest and has the maximum loop diameter, can prevent the compaction of the subsequent coils in the long term.

The Validity of FCP ≥ 32% as a Cutoff Value

The validity of FCP ≥ 32% as a cutoff value requires discussion. The worldwide consensus regarding the minimum VPD required for adequate occlusion is approximately 25%,^{9,31,32} which is compatible with our study. Therefore, if we try to satisfy both of these conditions, FCP ≥ 32% and VPD ≥ 25%, the minimum FVPD required for better long-term outcomes should be 8% (25% multiplied by 0.32), which is feasible in most of the cases other than giant aneurysms. Based on these calculations, we believe FCP ≥ 32% is quite reasonable and realistic. Also in our study, it was demonstrated that the correlation value for FCP and VPD was -0.055 ($p = 0.394$) as in Fig. 2, whereas the correlation value for FCP and FVPD was 0.742 ($p < 0.001$) in post hoc analysis; that is to say, more FVPD resulted in more FCP. Combined with this finding, one of the clinical applications of this study would be that

FCs with FVPD > 8% should be selected, and in cases in which FVPD > 8% is not feasible, the largest insertable coils should be selected to increase FCP.

The Predictive Scoring System

We proposed the simplest predictive scoring system based on aneurysm size and FCP, due to limited numbers in this study. The estimation of recurrence rate can be used to apply the tailored follow-up strategy for each patient. For instance, the lowest recurrence group may only need annual or biyearly MRAs, while the highest recurrence group should be investigated at least biannually with MRAs or angiograms.

The Advantage of FCP Over VPD and FVPD as a Predictor of Long-Term Outcomes

VPD was reported to be significant,^{9,31,32} or relatively insignificant,^{3,30} for aneurysmal recurrence in previous studies. In our study, VPD was significantly related to recanalization in general, but was not a significant factor for retreatment. Moreover, another disadvantage of VPD is that it is vulnerable to error in volume estimation.²⁷ FCP overcomes these shortcomings, and the fact that FCP plays a more significant role in long-term aneurysmal occlusion than VPD does indicates that the finishing coils that are deliberately inserted to increase VPD by just a small percentage may play a less critical role than FCs, or are even harmful because they may increase the risk of intraoperative rupture, as discussed elsewhere.^{30,34} In other words, how we achieved a certain VPD is much more important than what the actual VPD was.

Interestingly, in our analysis, FVPD as a continuous value or FVPD with any cutoff value was not able to predict recanalization or retreatment with statistical significance in multivariate analysis. Again, this is possibly due to error in volume estimation, but one of the potential interpretations for these findings is that FCP is multifactorial in a sense that its denominator is the total volume of

FIG. 1. Rate of aneurysmal recurrence for recanalization (left) and retreatment (right) based on the scoring system described in this article.

FIG. 2. The distribution of FCP and VPD, using FCP < 32% and VPD < 25% as cutoff values for aneurysmal recurrence.

coils that were actually insertable, which can adjust the factors including difficulty of the cases and morphology of aneurysms, whereas the denominator of VPD and FVPD is the volume of aneurysms, which only allows us to argue in a simplistic way. In other words, the accomplishable VPD and FVPD vary in each case, even if the aneurysmal volume of each case is the same due to several other factors, but FCP potentially allows us to eliminate these confounding factors.

Limitations of the Study

One of the relevant factors that should be discussed is the risk of intraoperative rupture due to the excessive FC volume. In fact, all of the 4 events of intraoperative rupture in our series did not happen during FC insertion, which

limited our analysis of the relationship between FCs and intraoperative rupture. Also, this small number of cases with intraoperative rupture makes it impossible to complete a further analysis. However, several studies reported the significance of FCs for intraoperative rupture.^{10,11,30} Hence, future studies to determine the maximal FVPD from the standpoint of preventing intraoperative rupture are warranted. Other limitations of this study included the limited numbers of aneurysms, single center analysis, and exclusion of hydrogel coils, which are now considered indispensable devices worldwide. Our future goal is to understand the role an FC plays in aneurysmal occlusion by using aneurysmal models and to discover what kind of FC is more appropriate for both better long-term outcomes and successful insertion by further analyzing the patient data.

TABLE 4. Comparison between FCP and VPD*

Variable	Mean FCP (%) ± SD	p Value	Mean VPD (%) ± SD	p Value
Immediate angiographic outcome		0.694		0.001
Raymond Score 1	36.9 ± 15.3		32.3 ± 7.8	
Raymond Score 2	35.6 ± 14.2		29.9 ± 8.2	
Raymond Score 3	37.4 ± 13.9		26.9 ± 8.5	
Angiographic outcome at 1-yr follow-up		<0.001		0.008
Raymond Score 1	36.8 ± 13.3		29.7 ± 9.2	
Raymond Score 2	39.5 ± 15.2		28.7 ± 8.0	
Raymond Score 3	27.8 ± 9.8		24.3 ± 6.2	
AUC for retreatment	0.785 (FCP)		0.632 (VPD)	0.040†
AUC for recanalization	0.704 (FCP)		0.643 (VPD)	0.394†

* Values are mean ± SD except for the rows with AUC values.

† p value for the comparison of AUC between FCP and VPD.

Conclusions

FCP, which is equal to the FC volume as a percentage of the total coil volume, and is unaffected by the morphology of the aneurysm or the measurement error in aneurysm length, width, or height, is a novel predictor of recanalization and retreatment and is more significantly predictive of retreatment than VPD. To select FCs large enough to meet the condition of $FCP \geq 32\%$ is a potential relevant factor for better long-term outcomes. These findings support our hypothesis that the FC is a significant factor for aneurysmal recurrence.

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Disclosures

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Author Contributions

Conception and design: all authors. Acquisition of data: Ishida. Analysis and interpretation of data: all authors. Drafting the article: Ishida. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Matsumaru. Statistical analysis: Ishida. Administrative/technical/material support: Matsumaru. Study supervision: Matsumaru, Sato.

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