

**Efficacy of comparing coil behavior and distribution
using the silicone aneurysm model:
difference of coil distribution in the early filling stage**

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ABSTRACT

This study sought to establish an experimental aneurysm model of visualizing coil insertion using radiolucent nylon coils. Moreover, this study aimed to clarify the characteristics and differences of each coil and use them clinically as indices of coil selection. The coil insertion test was performed on the 10 mm spherical silicone aneurysm model filled to a nylon coil volume embolization ratio of 11.8%. Five types of coil were randomly tested six times, and the distribution of the coils was analyzed by fluoroscopy imaging. Indices of “Area (mm²),” “Feret’s diameter (mm),” and “Circularity” were calculated from the fluoroscopic images. Among the indices, only “Area” showed a significant difference between coils ($p = 0.002$). On multivariate analysis, “Area” of the ED Infini was larger than those of Target XL soft and Galaxy G3 ($p = 0.018$ and 0.026 , respectively). Furthermore, the area of the 360 soft was larger than that of G3 ($p = 0.049$). Analysis of the correlation between these values and the coil configuration showed that “Area” was negatively correlated with the stock-wire diameter ($r = -0.50$; $p = 0.004$) and primary coil configuration ($r = -0.65$; $p < 0.001$). When inserting the coils in the early stage, although the difference between each coil is relatively difficult to obtain, knowledge on the proper use of the coils with differences in characteristics can help in selecting the coil most appropriate for the conditions.

Keywords: filling coil, aneurysm model, coil distribution

Abbreviation:

VER: volume embolization ratio

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INTRODUCTION

The embolization process and coil selection are divided into three stages: covering the aneurysmal wall with stable framing coils, consistently embolizing the inside with filling coils, and tightly embolizing limited residual space using soft finishing coils.¹ In the coil embolization of intracranial aneurysms, volume embolization ratio (VER) is one of the most objective indicators for estimating

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embolization success, such as angiographic results by digital subtraction angiography.² High VER is important in preventing the recurrence and rupture of the treated aneurysms.^{3,4} To achieve high VER and effective embolization, coil selection according to the situation of the residual aneurysm size and shape is very important. Since a stable coil frame by optimal initial coil selection leads to high total VER and subsequent recurrence-free results, initial coil selection is important in preventing recurrence.⁵ In the embolization of a large aneurysm, since it is impossible to make a stable coil frame by only the initial coil, it is necessary to utilize not only the initial coil but also the filling coils to make a stable frame. However, there are no reports on coil selection at this stage.

Since multiple manufacturers have contributed to the growth of coil technology, various filling coils used for similar situations have been released. The differences among these coils are unclear because coil insertion behavior and distribution are not indicated by already detached coils. Specifications during deployment, such as stiffness, volume, and behavior, are evaluated only during the original benchmark test performed by each manufacturer. No methods have been established to compare these coils centrally in the same condition.

This study aims to clarify the characteristics and differences among the coils in the condition of the early filling stage of the embolization by objective and unitary comparison and use these clinically as indices for coil selection. Moreover, this study aimed to establish an experimental aneurysm model of visualizing coil insertion using radiolucent nylon coils.

METHODS

Aneurysm model

The aneurysm model was made of silicone with a spherical diameter of 10 mm. The diameter of the neck was 1 mm (Figure 1). Sixty centimeters of 0.0124 inch radiolucent nylon coil and 20 cm of 0.0122 inch radiolucent nylon coil were inserted into the aneurysm model until the VER was 11.8%. Under these conditions, the experimental coil insertion test was performed.

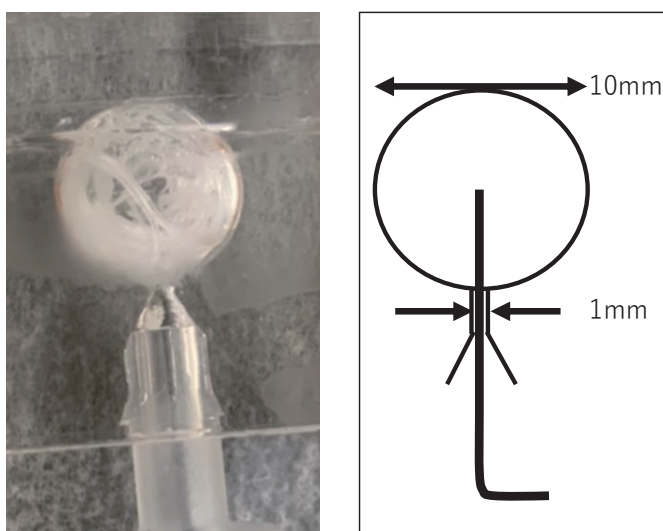


Fig. 1 Schema of the silicone aneurysm model

The model had a spherical diameter of 10 mm. The diameter of the neck was 1 mm. The tip of the microcatheter was placed at the center of the aneurysm model.

Experimental coil insertion test

An Excelsior SL10 microcatheter (Stryker, Fremont, CA, USA) was used for the delivery catheter, and the tip was positioned at the center of the aneurysm. The coils were continuously inserted 20 cm (1 cm/s) by machine. The insertion test was performed using the following five products: ED Coil Infini Soft (Infini) 16 mm × 20 cm (Kaneka Medics, Osaka, Japan); Target 360 soft (360) 8 mm × 20 cm (Stryker); Target XL soft (XL) 8 mm × 30 cm (Stryker); VFC 6–10 mm × 20 cm (MicroVention Terumo, Tustin, CA, USA); and Galaxy G3 8 mm × 24 cm (Cerenovus, Miami, FL, USA). The insertion test was performed under fluoroscopy, and the insertion of 20 cm of coil into the aneurysm model with was recorded. The insertion test was performed six times randomly for all coils.

Evaluation of the test

The fluoroscopic images were analyzed using Image J ver. 1.51 image analyzing software (National Institutes of Health, Bethesda, Maryland, USA). The images were converted to 8-bit Tagged Image File Format and binarized to extract only the coil images. “Area (mm²),” “Feret’s diameter (mm),” and “Circularity” were calculated by particle analysis and compared between coils. “Area” was defined as the area surrounded by the outer periphery of the coil. This indicates the amount of remaining space, in which the coil is distributed. “Feret’s diameter” was defined as the maximum caliper diameter of the coil mass. This indicates the actual amount of remaining space, in which the coil is actually distributed. “Circularity” is calculated by $4\pi \times \text{“area”} / (\text{“perimeter”})^2$. The distribution of the coil is closer to a circle, and as the value becomes larger, it gets closer to one. An irregular shape distribution and a smaller circularity value indicate the coil interferes with the already detached coil and penetrates into the confined gap of the detached coil (Figure 2).

In addition, the correlations between these data and configurative specifications of the coils, including stock-wire diameter, primary and secondary coil configurations, and the K factor, were evaluated. The K factor is the physical properties of springs, and is calculated using the stock-wire diameter and primary coil configuration (K factor \propto stock-wire diameter/primary coil configuration). Furthermore, it is proportional to the stock-wire diameter and inversely proportional to the primary coil configuration.⁶

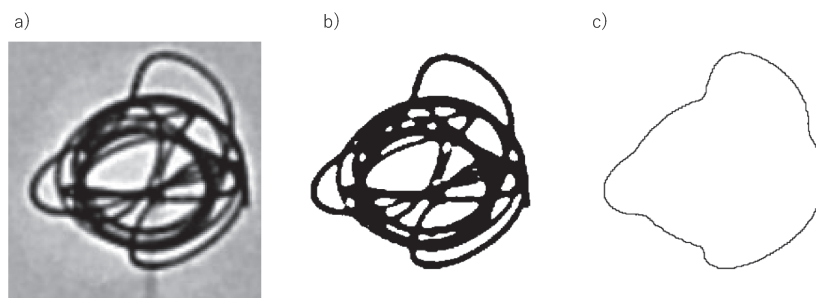


Fig. 2 Analysis of the fluoroscopic image

Fig. 2a: Fluoroscopic image of the inserted coil and the aneurysmal model.

Fig. 2b: The image of extracted coil by converted to 8-bit Tagged Image File Format and binarized.

Fig. 2c: Parameters were calculated by particle analysis. “Area”, “Feret’s diameter”, and “Circularity” were 43.995 mm², 8.679 mm, and 0.71 respectively.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation. Continuous variables between groups were compared using the Kruskal–Wallis test, and each group was compared by multiple comparison using the Dann–Bonferroni test. Pearson’s correlation coefficient test was used to analyze the correlation between coil distribution and coil specifications. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA).

RESULTS

The experimental coil insertion test was randomly performed regardless of the coil, and the state was recorded (Figure 3).

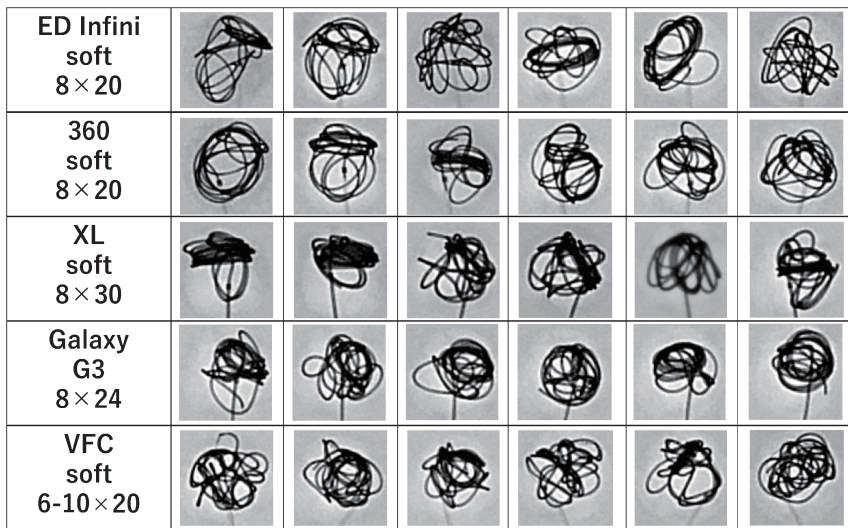


Fig. 3 Fluoroscopic images of the coil insertion test
Each coil was randomly inserted six times.

Area

The average value of the area ranged from 34.7 to 44.8 mm². Infini had the largest area, followed by 360, VFC, XL, and G3 (Figure 4a).

Feret’s diameter

The average Feret’s diameter ranged from 7.9 to 8.8 mm. Infini had the largest diameter, followed by 360, VFC, XL, and G3 (Figure 4b).

Circularity

The average circularity ranged from 0.60 to 0.72. G3 had the highest circularity, followed by 360, Infini, XL, and VFC (Figure 4c).

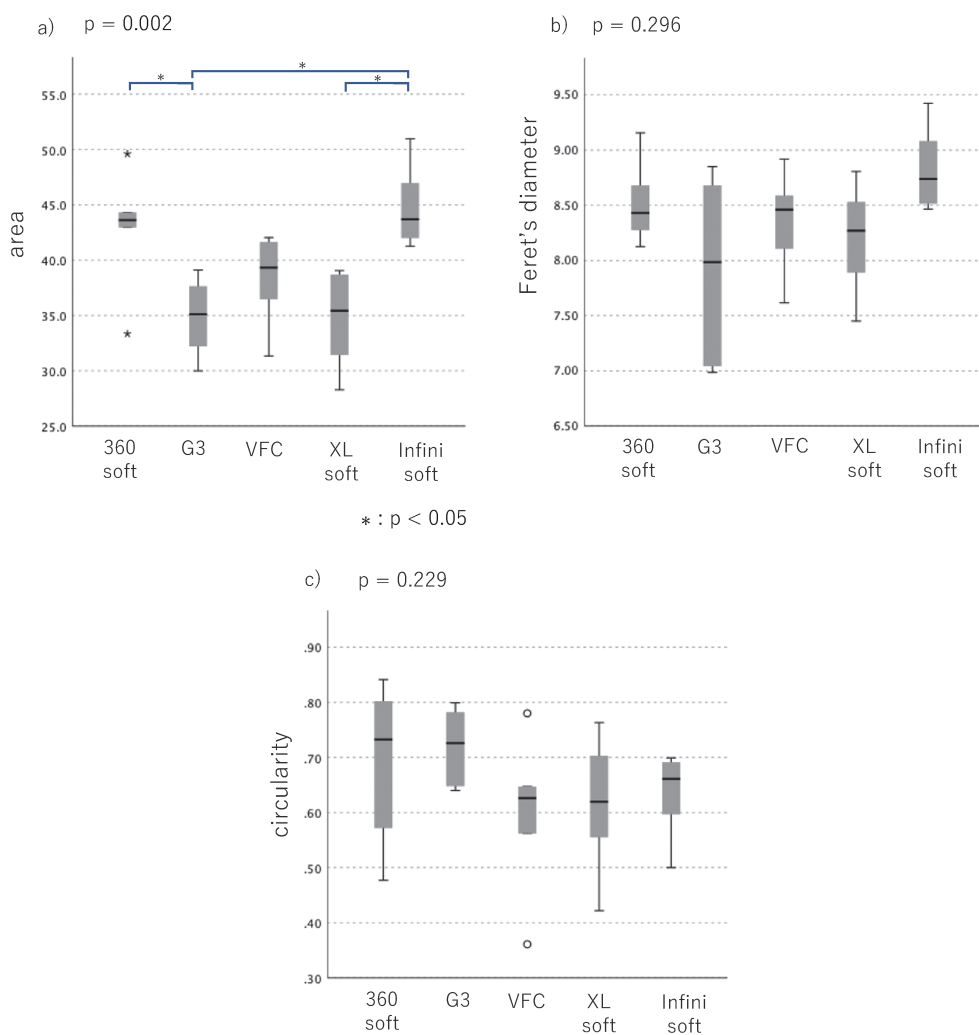


Fig. 4 Results of the calculated parameters

Fig. 4a-c: Figure revealed a) area, b) Feret's diameter, and c) circularity, respectively. Only area differed significantly among the coils ($p = 0.002$). By multiple comparison test, only area varied significantly between some coils. The area of the ED Infiniti is larger than XL soft, and G3 ($p = 0.018$, and 0.026 respectively). The area of the 360 soft is larger than G3 ($p = 0.049$). Feret's diameter, and circularity did not differ significantly among the coils ($p = 0.296$ and 0.229 , respectively).

Comparison between coils

The Kruskal–Wallis test revealed significant differences in area among the coils ($p = 0.002$). However, no significant differences were found in Feret's diameter and circularity ($p = 0.296$ and 0.229 , respectively). Multivariate analysis for non-parametric data using the Dunn–Bonferroni revealed only area varied significantly between some of the coils. The area of the Infiniti was larger than those of XL and G3 ($p = 0.018$ and 0.026 , respectively), whereas the area of the 360 soft was larger than that of G3 ($p = 0.049$) (Figure 4a).

Correlation with coil specifications

Area, Feret's diameter, and circularity had no correlation with most of the coil specifications. However, area was negatively correlated with stock-wire diameter ($r = -0.50$; $p = 0.004$) and the primary coil configuration ($r = -0.654$; $p < 0.001$) (Figure 5).

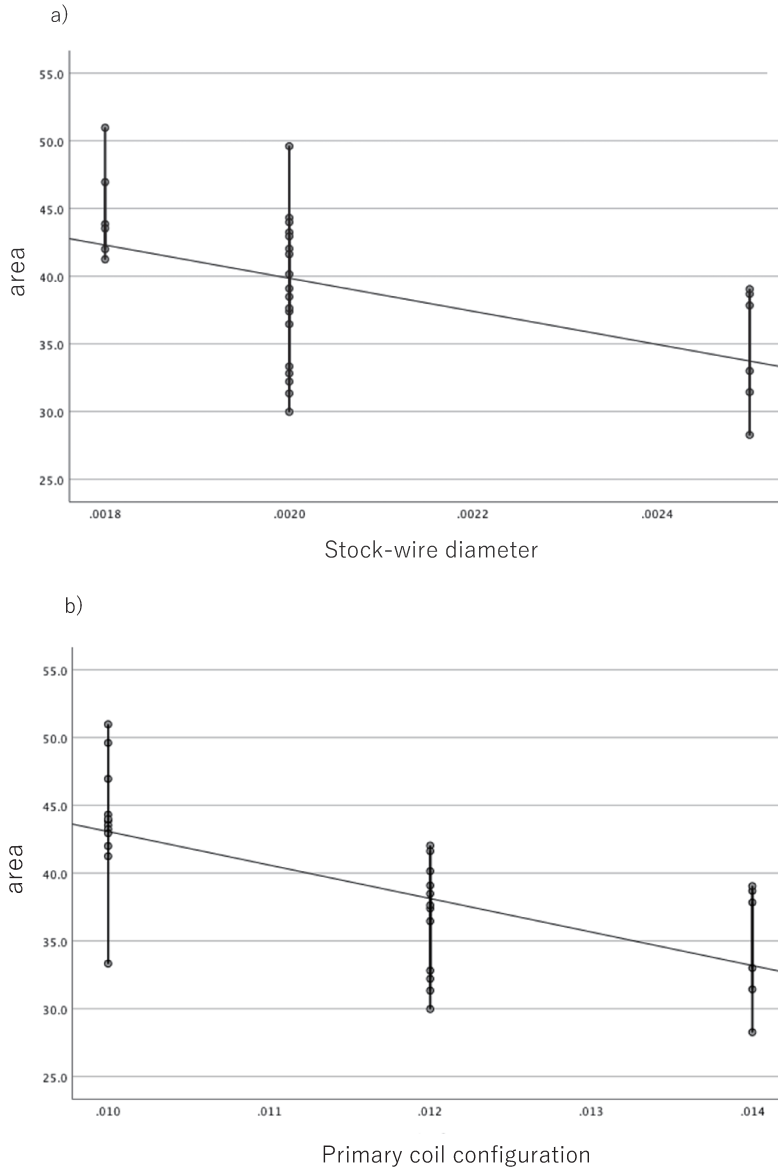


Fig. 5 Correlation between the coil configuration and coil distribution area

Fig. 5a: The coil distribution area was negatively correlated with the stock-wire diameter ($r = -0.50$; $p = 0.004$).

Fig. 5b: The coil distribution area was negatively correlated with the primary coil configuration ($r = -0.65$; $p < 0.001$).

DISCUSSION

Differences in coil distribution and comparison with previous experiments

For beginners, coil selection is based on the expert opinion, mostly by their senior doctor, which express nuances of the coil behavior, because there is no objective comparison method. It indicates the evaluation is not objective, and not always correct. In our experiment, we selected coils with a secondary diameter of 8 mm for coils with products of lineup in 1 mm increments in early-stage insertion of the filling coil into the aneurysm. Infini and VFC did not have various size lineups in 1 mm increments but some standard sizes, and they were characterized by being suitable under various sizes of residual cavity without considering the size of secondary coil diameter. These were also included in our experiment, since these coils were selected in the same situation. The Kruskal–Wallis test revealed significant difference between different types of coils. However, multiple comparison showed significant differences only in the coil distribution area between some coils. XL and G3 were especially found less likely to be distributed in a wide area. On the other hand, Infini and 360 showed a tendency to easily spread to a wider area. Feret's diameter and circularity did not differ significantly among the coils.

We previously reported similar examinations under different conditions. In the latter stage of the filling of a small aneurysm (VER 25%) and the finishing (VER 30%), significant differences between coils were observed not only in area, but also in circularity and centroid.^{7,8} Complex-shaped coils generally have high area and circularity scores compared with other coil shapes, which indicate the need to provide a balanced distribution of coils.^{7,8} On the other hand, low shape memory coils have low circularity and high centroid scores, which indicate that such coils tend to penetrate into the confined tiny gap of the detached coils.⁸ Although no inconsistencies with previous results were found regarding the characteristics of the individual coils, the differences between the coils seemed more relatively difficult to determine in this early filling condition compared with those under a relatively high VER. This is because most types of coils can be easily deployed compared with the end stage of filling or embolization of a small aneurysm. However, selecting a coil without considering the detailed embolization status, as most types of coils can be easily deployed, may lead to incomplete embolization by compartmentalization or frame destruction by coil protrusion. Creating a stable coil frame is important for preventing incomplete occlusion and recurrence. Neki et al reported the importance of achieving a VER of 17.5% in the first coil, and Ishida et al reported 10% in the first coil.^{5,9} These reports indicated that a stable frame by optimal initial coil selection leads to total high VER and subsequent recurrence-free results.^{5,9} However, in the embolization of a large aneurysm since the aneurysmal volume becomes large, stable frame using sufficient VER could not be achieved only with the initial coil, and it is necessary to reinforce initial frame coil with the following filling coils. Therefore, coil selection in the early filling stage is also important to avoid incomplete embolization or recurrence. We believe it is important to consider some differences that were revealed in this experiment when selecting coils.

In this study, Infini, which is a coil with a low shape memory large helical shape, showed a high distribution area and would therefore suit for filling under various situations. It is designed to spread outward widely to the side of the aneurysmal wall and reduce the compartment space.¹⁰

The 360, which is a complex-shaped coil, is designed for balanced distribution, concentric filling, and neck coverage.¹¹ It also showed a relatively high distribution area in this study, which is consistent with the product description and with the findings of our previous studies.^{7,8} Thus, 360 would also suit for filling in various situations.

Conversely, G3 and XL showed lower distribution areas. XL is a 3D, complex-shaped coil, but was less likely to show a high distribution area. This is consistent with our results that the

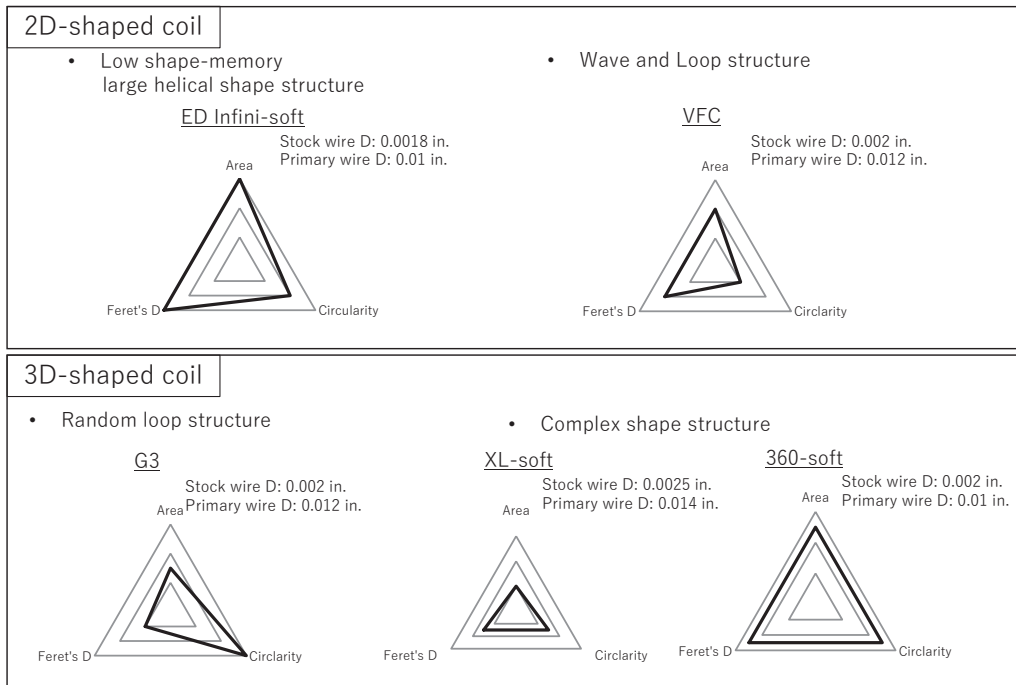


Fig. 6 Characteristics and radar charts of the coils

The radar charts are plotted according to the rank of the values.

D: diameter
in: inches

primary coil configuration is negatively associated with the area. Coils with a large primary configuration are less likely to spread into the narrow gap of the detached coil. In cases where framing coils seem to be stable enough, the XL soft may have the advantage of obtaining a higher VER by filling the core open space.

G3 has a random loop design and it pursue a different path each time it is deployed. It was manufactured to occlude multi-lobular, irregular-shaped aneurysms by seeking open space to fill concentrically, from the periphery to the core.¹² In our model, although G3 was not widely distributed, G3 was the only coil with a Feret's diameter that was less than 8 mm in the coils and 8 mm in the 2nd coil configuration. This is a specific finding in our study. Depending on the situation, it possibly does not interfere with the detached coil and may be distributed concentrically in an open space, which may be advantageous in cases where the framing coil is unstable.

As per the product description VFC is designed as a unique wave-and-loop structure, in which the wave structure seeks and spreads to the available narrow space.¹³ However, in our experiments, the coil distribution area of VFC was lower than those of the other coils. The condition of the examination and the early phase of the filling, may not be suitable for VFC. Further investigations are needed to examine the behavior of VFC under various conditions (Figure 6).

Aneurysm model and coil insertion test

In the coil insertion test, each trial was carried out continuously without re-inserting the radiolucent nylon coil. However, no significant change was observed in the radiolucent coils after each insertion. Therefore, the conditions of each trial did not vary significantly. The strong

point of this model and the coil insertion test is that all coils can be compared centrally in any situation by adjusting the length of the radiolucent coil, the rigidity of the radiolucent coil, or the insertion speed. The experimental model and the evaluation method were the same as those in previous reports,^{6,7} but we could further clarify the differences of coil characteristics between coils at the early stage of filling. In this study, we focused on, by adjusting the VER, coil selection and insertion speed to the similar condition of early filling stage. Although it will be easier to choose the appropriate coil instinctively by gaining experience in coil embolization, the results of this aneurysm model study help less experienced surgeons understand coil characteristics and differences. When a new coil is released in the future, our aneurysm model will help provide an understanding of the differences in coil behavior before clinical use by providing a means of comparison with existing coils. Moreover, it will be possible to expand the experiments to the differences in coil behavior due to insertion technical differences.

Limitations

This study has some limitations. First, since the aneurysm model consists of silicone aneurysm wall and nylon coils, which have different friction coefficients from the actual embolization coil, the actual coil behavior may not reflect the results of the model. However, no objective data that can be used as an index for coil selection are currently available, which makes our findings helpful in some situations. Second, this test could not be evaluated three-dimensionally. However, it may be sufficient since we always perform coil embolization based on two-dimensional information. Evaluation from two directions and three-dimensional evaluation may show more accurate results, which should be the focus of future studies.

CONCLUSION

We compared the behaviors and distributions of selected coils under the same conditions. In early-stage insertion of the filling coil into the aneurysm, our experimental aneurysm model showed no difference between some coils. However, this study showed that significant differences were observed between some coils, which indicates that these differences need to be understood in order to use them in the appropriate situations. Infini and 360 tended to occupy a larger area, whereas XL and G3 tended to stay within a smaller space. Moreover, stock-wire diameter and primary coil configuration were negatively correlated with the coil distribution area. Using our experimental coil insertion test, similar coils can be compared under the same situation, rather than judging only by catalog specifications or benchmark tests of each product company. This enables a deeper understanding of the characteristics of the various coils for the selection of coils best suited to the condition.

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ADDITIONAL CONTRIBUTION

Data analyses were performed independently by the authors.

DISCLOSURE STATEMENT

We declare that we have no conflict of interest.

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