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Evaluation of the Straightening Phenomenon of Various Types of Coils

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Abstract

The straightening phenomenon is known as a cause of catheter kickback in the late phase of coil embolization. The mechanism is supposed to be the relative shortage of the stretch resistance (SR) line, and it occurs when a coil is folded too small. Among many SR coils available, there should be a coil-specific tendency to cause this phenomenon. Here, we conducted an in-vitro experiment to know which coil is the most resistant to the straightening phenomenon. We developed an experimental model to reproduce the straightening phenomenon. Five different coils (Axium Prime, ED Coil, Hypersoft, SMART Coil, and Target 360 nano) of the same size (3 mm × 6 cm) were investigated for five times each. Resistance to the straightening phenomenon, which is represented by the insertion length at the onset of the phenomenon, was compared among coil types. The straightening phenomenon was successfully observed in all insertions. Insertion lengths were significantly different among coil types ($p = 0.013$). The insertion length of ED was the longest (mean ± SD, 27.0 ± 8.3 mm), which means the most resistant to the phenomenon. Axium was second (21.6 ± 7.0 mm), followed by Target (15.8 ± 6.9 mm), Hypersoft (13.8 ± 5.8 mm), and SMART (12.4 ± 4.7 mm). Difference between ED and Hypersoft ($p = 0.037$) and difference between ED and Smart ($p = 0.018$) were significant. ED coil was the one with the most resistance to the straightening phenomenon. Selecting the optimal coil is the key to avoid the phenomenon.

Keywords: coil, aneurysm, embolization, straightening phenomenon

Introduction

Since its introduction in the early 1990s,[1,2] the detachable coil has become the most common device in neuro-endovascular treatment. The coil stretching, also mentioned as "unraveling," was frequently reported as a potential complication of coil embolization especially in the early days.[3–7]

Today, almost all coils have a countermeasure for stretching. A solid wire, the so-called stretch resistance (SR) line, is set inside the primary coil to prevent the breakage of the coil structure. However, the existence of the SR line induced a new potential complication, the straightening phenomenon.

The mechanism of the straightening phenomenon is as follows (Fig. 1). An SR coil is consisted of primary coil filaments and an SR line running through them (A). When a coil is inserted, the SR line is not positioned at the very center of the primary coil lumen. It is running along one side of the luminal wall to another (B, arrowheads). This meandering course means that the SR line runs excessive length compared to the coil itself. When an SR coil is folded too small, this excessiveness can lead to the significant shortage of the SR line as the folding frequency increases. The shortage results into the lost flexibility at the terminal portion of the coil (B, arrow). The coil behaves like a stiff wire in this situation, and the microcatheter is prone to kickback.

The straightening phenomenon is mainly observed in the finishing scene of embolization. This is because actual space is invisible due to the previous

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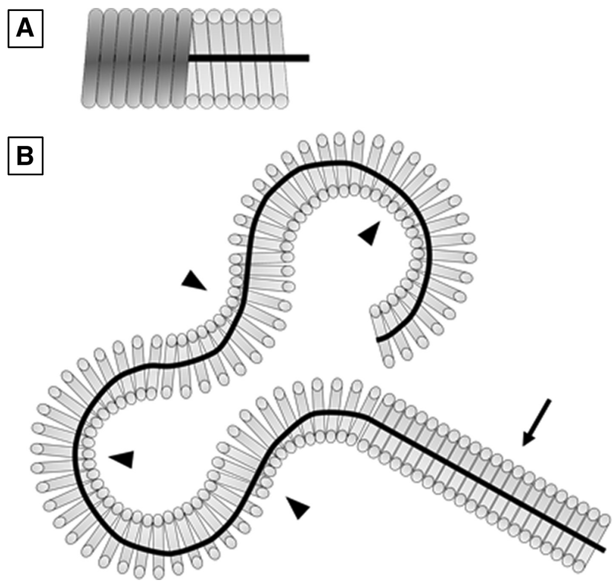

Fig. 1 A schema of the straightening phenomenon. (A) An SR coil is consisted of primarily coil filaments and an SR line running through them. (B) In actual embolization, the SR line is running along one side of the primary coil wall to another (arrowheads). The shortage of the SR line results in the lost flexibility in the coil tail (arrow).

coils on the later stage of the embolization, and too large or long coil can easily be selected.

Recently, a variety of finishing coils are introduced by many companies. These coils differ from each other in structures or materials,[8,9] so there should be a coil-specific tendency to cause the straightening phenomenon. Here we conducted an in-vitro experiment to compare resistance to the straightening phenomenon among some finishing coils.

Materials and Methods

The authors developed an experimental model to simulate the course of the straightening phenomenon. The system was consisted of a silicon-made aneurysm model and an auto-insertion device (Fig. 2). At first, we tried with various sizes of simple spherical aneurysm models, which would not work; coils should be folded very small to induce the straightening phenomenon. But with a small aneurysm model, catheter kickback due to the excessive coil density happens before the straightening phenomenon. The ideal aneurysm model should possess a small diameter as well as a large enough volume. Then we made up a beads-shaped aneurysm model which achieved both of them. The diameter of each aneurysm is 1.5mm, which is half of the second loop diameter of the coils examined in this study.

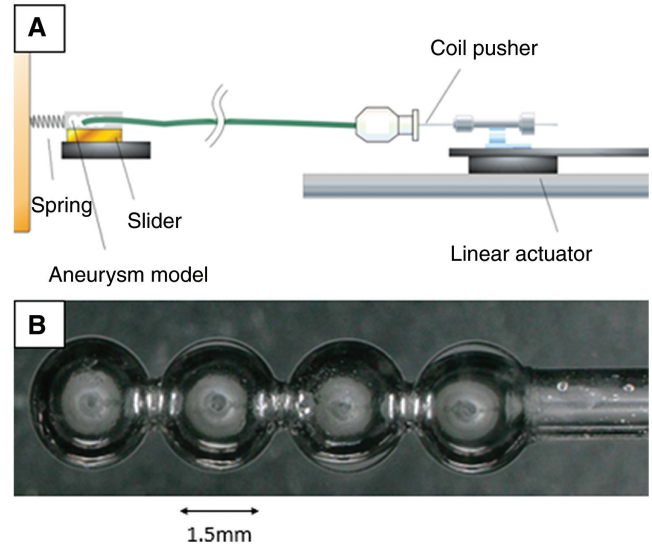

Fig. 2 A scheme of the experiment. (A) A whole image of the experimental system. The system is consisted of an aneurysm model and an auto-insertion device. (B) An enlarged view of the aneurysm model.

An Excelsior SL-10 straight microcatheter (Stryker, Kalamazoo, MI, USA) was placed at the neck of the most distal aneurysm. The aneurysm model is held with a spring to keep the catheter position to a certain degree and automatically move with an excessive pressure. Coils of a certain size (3 mm in diameter and 6 cm in length) were inserted automatically by 2mm/sec via a linear actuator. Five types of SR coils from different companies were tested in this experiment: Axium Prime ES 3 mm–6 cm (Medtronic, Minneapolis, MN, USA), ED Coil Extrasoft 3 mm–6 cm (Kaneka Medics, Osaka, Japan), Hypersoft 3D 3 mm–6 cm (MicroVention/Terumo, CA, USA), SMART Coil Complex Extra Soft 3mm–6cm (Penumbra, CA, USA), and Target 360 nano 3 mm–6 cm (Stryker). Five individual coils for each one of these five types, 25 coils in total, were examined.

In the course of insertion, the microcatheter was withdrawn from the aneurysm model due to the mobility of the model. We identified the onset of the straightening phenomenon when coils acted linearly more than 1.5 mm (equal to the aneurysm diameter). The insertion length at the onset of the straightening phenomenon was recorded and compared among coil types (Fig. 3). A longer insertion length at the onset means more resistant to the straightening phenomenon.

One-way ANOVA was performed to assess an overall comparison, and Tukey's post hoc test was used for comparisons between each pair of five coils.

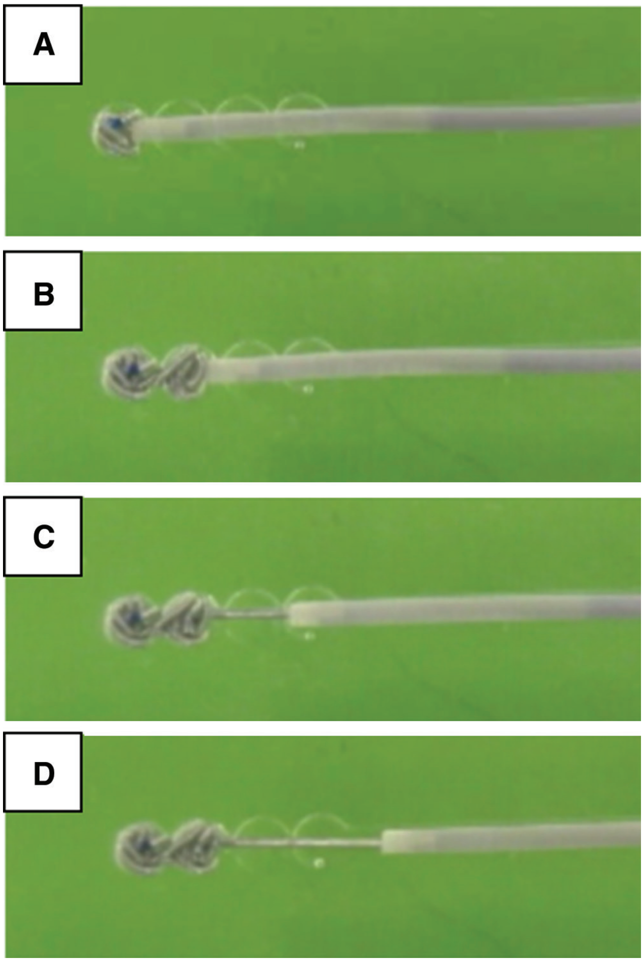

Fig. 3 **Representative images of the experiment. (A, B) A coil is automatically inserted into the aneurysm model. (C) The straightening phenomenon happened, and the coil acted linearly like a stiff wire. The onset of the straightening phenomenon was defined when the linear part of the coil reached 1.5 mm. The insertion length at this point was recorded. (D) The coil continued to act like a straight wire.**

Results

The straightening phenomenon was successfully observed in every trial (Table 1). There was a significant difference in insertion length among coil types ($p = 0.013$). ED coil had the longest insertion length (mean ± SD insertion length, 27.0 ± 8.3 mm), which means the most resistant to the straightening phenomenon. Axium prime 3D was second longest (21.6 ± 7.0 mm), followed by Target 360 nano (15.8 ± 6.9 mm), Hypersoft 3D (13.8 ± 5.8 mm), and SMART ES (12.4 ± 4.7 mm). As for pairwise comparisons, ED coil showed a significant dominance over Hypersoft 3D ($p = 0.037$) and SMART ES ($p = 0.018$, Fig. 4).

Discussion

The straightening phenomenon was first reported by Miyachi et al.[10] as a factor of microcatheter kickback in the late phase of embolization. Although this phenomenon is sometimes observed in actual embolization, little is studied so far. This report is the first one to investigate into the coil-specific tendency to cause the straightening phenomenon. The length of the SR line of each coil should be the most determinant factor for development of the phenomenon. But the data of the SR length are generally confidential information and unavailable for us. In addition, happening of the straightening phenomenon also highly depends on the circumstance. So we deemed that a reproduction model was necessary to investigate into this phenomenon.

We created the beads-shaped aneurysm model to reproduce straightening phenomenon. This strange shape is based on the actual situation because the straightening phenomenon occurs in the finishing stage of embolization, where the invisible space consists of many small compartments.

The straightening phenomenon may lead to some clinical complications. Continuing coil insertion with elevated pressure can result in perforation, and the repositioning of the kick-backed catheter possesses risks. Prevention is important, and the selection of the coil is the key. Small, short, and those with reluctance to the straightening phenomenon is optimal in the late phase of embolization.

Table 1 **Insertion lengths of each coil**

	1st coil	2nd coil	3rd coil	4th coil	5th coil	Mean ± SD
Axium Prime ES	20 mm	12 mm	19 mm	28 mm	29 mm	21.6 ± 7.0
ED coil Extrasoft	31 mm	14 mm	36 mm	25 mm	29 mm	27.0 ± 8.3
Hyper Soft 3D	10 mm	8 mm	15 mm	13 mm	23 mm	13.8 ± 5.8
SMART Coil	7 mm	11 mm	15 mm	10 mm	19 mm	12.4 ± 4.7
Target 360 Nano	7 mm	10 mm	19 mm	20 mm	23 mm	15.8 ± 6.9

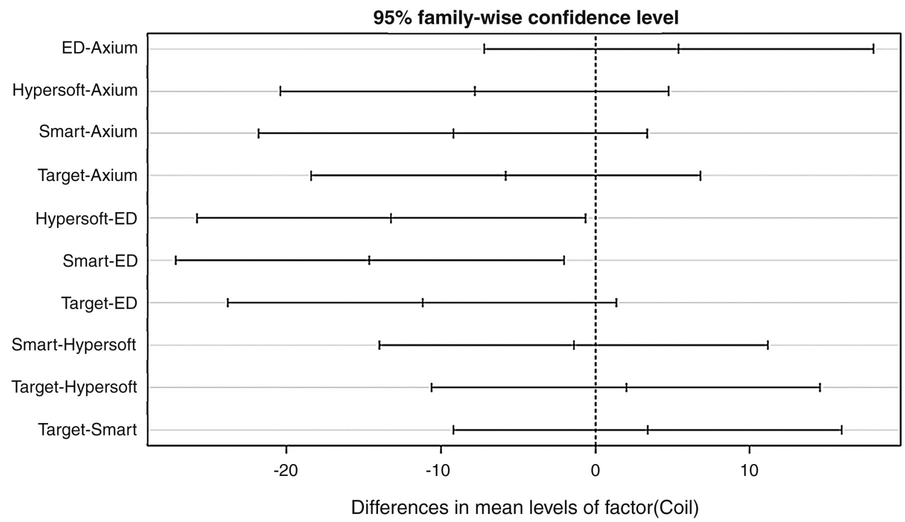

Fig. 4 Results of pairwise comparisons.

The result of this study could be helpful in selecting the coil type.

In this study, ED coil showed the most resistance to the straightening phenomenon. This superiority could be accounted for the special structure of this coil. The SR line is arranged in wave shape in this coil, achieving a longer SR line compared to the coil length. This delicate workmanship is made for the purpose of giving coils resistance to the straightening phenomenon, and it was demonstrated well in this study.

This study has some limitations. First, the study volume is very small. Once the straightening phenomenon happened, the used coil was structurally broken, so each coil could be tested only once. This limited our study volume as low as five trials for each coil type. Second, the individual insertion length to face the straightening phenomenon had very wide range. It is because trivial differences of background elements such as catheter positioning or coil distribution influence the folding diameter of the coil, which is the most important factor to the phenomenon. Minor variations in the SR line length of the same product could be the factor for this, too. Although a significant difference among coil types was certified, the large variety of the length might damage the validity of the comparison. Last, the experimental model could be inadequate in various aspects. We used an auto-insertion system and a fixed microcatheter to avoid manipulation biases. But in actual embolization, we insert coils manually while adjusting the catheter position. This difference could substantially affect the coil behavior. Further data from actual embolization are awaited.

Acknowledgments

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Conflicts of Interest Disclosure

The authors declare the following potential conflicts of interest with respect to research, authorship, and/or publication of this article: Takashi Izumi received research grants from Kaneka Medix while conducting the study. The other authors have no personal or financial interest in any of the materials or devices described in this article.

References

1) Guglielmi G, Viñuela F, Dion J, Duckwiler G: Electrothrombosis of saccular aneurysms via endovascular approach. Part 2: preliminary clinical experience. *J Neurosurg* 75: 8–14, 1991
2) Guglielmi G, Viñuela F, Sepetka I, Macellari V: Electrothrombosis of saccular aneurysms via endovascular approach. Part 1: electrochemical basis, technique, and experimental results. *J Neurosurg* 75: 1–7, 1991
3) Cho JH: Endovascular rescue method for undesirably stretched coil. *J Korean Neurosurg Soc* 56: 364–367, 2014
4) Fiorella D, Albuquerque FC, Deshmukh VR, McDougall CG: Monorail snare technique for the recovery of stretched platinum coils: technical case report. *Neurosurgery* 57: E210; discussion E210, 2005

5) Lee CY: Use of wire as a snare for endovascular retrieval of displaced or stretched coils: rescue from a technical complication. *Neuroradiology* 53: 31–35, 2011
6) Standard SC, Chavis TD, Wakhloo AK, Ahuja A, Guterman LR, Hopkins LN: Retrieval of a Guglielmi detachable coil after unraveling and fracture: case report and experimental results. *Neurosurgery* 35: 994–998; discussion 999, 1994
7) Kwon OK, Lee KJ, Han MH, Ko YC: Coil breakage during aneurysm embolization. Case report. *Interv Neuroradiol* 8: 21–23, 2002
8) Marks MP, Tsai C, Chee H: In vitro evaluation of coils for endovascular therapy. *AJNR Am J Neuroradiol* 17: 29–34, 1996
9) White JB, Ken CG, Cloft HJ, Kallmes DF: Coils in a nutshell: a review of coil physical properties. *AJNR Am J Neuroradiol* 29: 1242–1246, 2008
10) Miyachi S, Izumi T, Matsubara N, Naito T, Haraguchi KI, Wakabayashi T: The mechanism of catheter kick-back in the final stage of coil embolization for aneurysms: the straightening phenomenon. *Interv Neuroradiol* 16: 353–360, 2010

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