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Optimum coil insertion speed of various coils in brain aneurysm embolization in vitro

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Abstract

A coil must comprise material with shape memory to perform optimal coil embolization. To achieve this, the alloy characteristics of the coil (hardness, shape, and thickness) must be understood. In this experiment, a catheter was fixed in the bright position and the movement of the coil was observed under a constant rate of insertion; the optimal insertion rate during clinical use was investigated. The first coil insertion speed was evaluated using simulated aneurysms in an in vivo arterial model. The results showed that the insertion force relates to the deployment shape of the coil, that the feedback through the force indicator using sound is very effective, and that the recorder is useful for analysis of coil embolization. The inserted coils during aneurysm embolization were able to wind uniformly within the aneurysm due to a variety of factors (guiding or micro-catheter position and kick-back phenomenon such as delivery wire). Optimal speed is achieved with proper coil design, which allows the coil to be inserted into the aneurysm. The shape and size of the aneurysm can help determine the necessary size and design of the coil that should be used during the optimal speed range. Aneurysm wall and coil characteristics are considered, along with the friction state of the coil (hardness, shape, and thickness), leading to improvements in safety during the insertion procedure at optimum speed.

Keywords

Intracranial aneurysm, aneurysm filling device, endovascular embolization, coil insertion speed

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Experimental purpose

For optimum coil embolization, the coil wire diameter, material, shape, shape memory, and alloy characteristics (hardness, shape, and weight) should be understood for the various coils available. We fully understand that the characteristics of each coil (hardness, shape, and thickness) are not the same.

This experiment used a fixed catheter tip and catheter position in an aneurysm to examine the optimal coil insertion speed and to observe the movement of the coil at a constant insertion speed in a clinical setting.

Method

In the aneurysm model, the parent vessel (diameter, 3 mm) aneurysms (diameter, 5.5 mm × 4.5 mm; neck, 3.5 mm) were created by aneurysm (polyvinyl alcohol). An Excelsior SL10 (pre-shaped 90°) micro-catheter was dehisced from within the micro-catheter using a micro-guide wire (Terumo GT12; pre-shaped 45°) and an aneurysm was created. The aneurysm was kept at a constant speed using a variety of coils and a linear actuator. Movement during the aneurysm was observed (Figures 1–4).

The following coils were investigated:

GDC 360 Standard (Stryker Neurovascular, Fremont, CA, USA)
GDC 360 Soft (Stryker Neurovascular, Fremont, CA, USA)
Matrix II 360 (Stryker Neurovascular, Fremont, CA, USA)
Target 360 Soft (Stryker Neurovascular, Fremont, CA, USA)
EDC InfiniSoft (Kaneka Medix, Osaka, Japan)
EDC10 Soft (Kaneka Medix, Osaka, Japan)
EDC14 Standard α-spiral (Kaneka Medix, Osaka, Japan)
Presidio (Johnson & Johnson Codman & Shurtleff, Raynham, MA, USA) Galaxy

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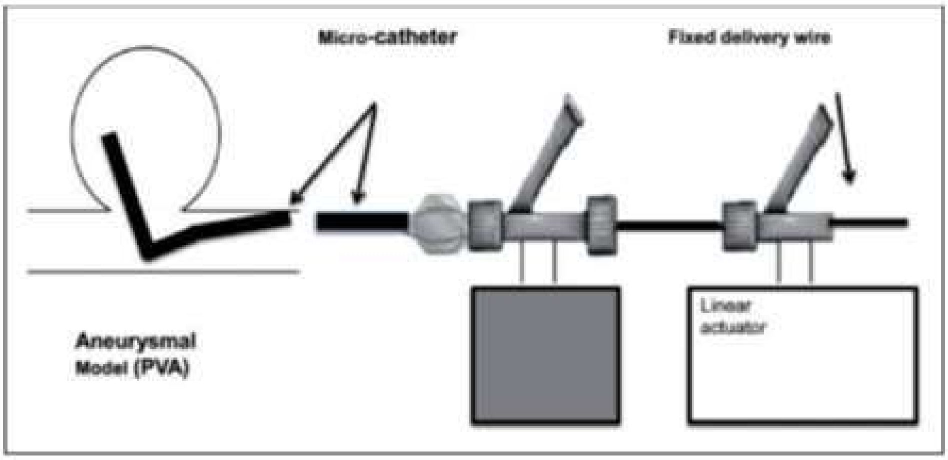

Figure 1. The indwelling fixed bright tip of the catheter and coil were inserted at a constant speed with the linear actuator. Instruments used: micro-catheter (Excelsior SL10 90°) and micro-guidewire (Terumo GT12 45°). Aneurysmal model (PVA) included the following: parent vessel, φ 3.0 mm; φ 5.5 mm × 4.5 mm; neck, 3.5 mm.

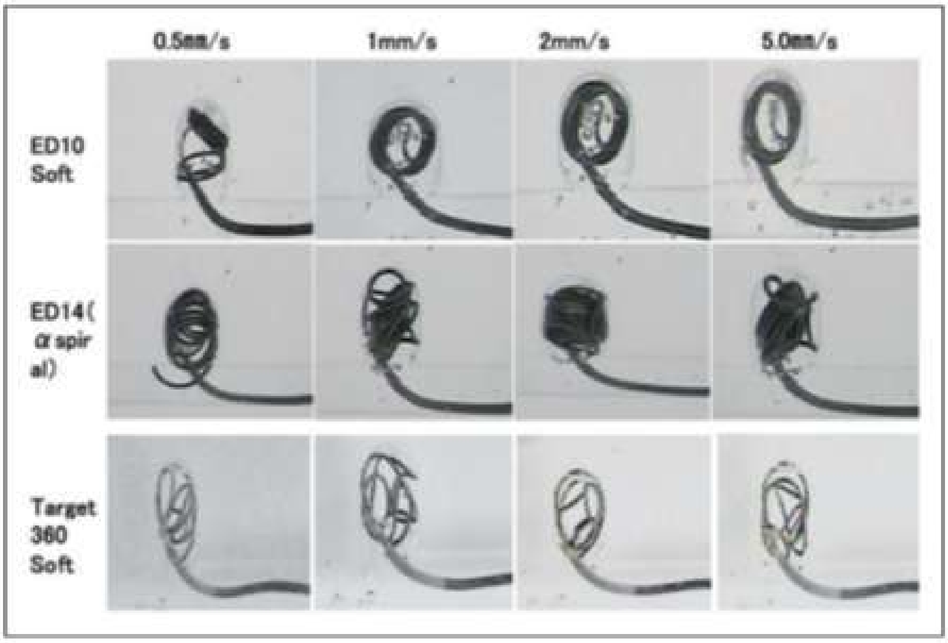

Figure 2. A typical photo of each coil in the present experiment. Axiom 3D coil is a very fine movement. For this reason, the characteristics of the coils, micro catheter-also considered to have changed due ether in motion and stationary status and the like.

Complex fill (Johnson & Johnson Codman & Shurtleff, Raynham, MA, USA)
Compass (MicroVention/Terumo, Austin, CA, USA)
Cosmos (MicroVention/Terumo, CA, USA)
Hydro10 (MicroVention/Terumo, CA, USA)
Variable Range Coils (VFC) (MicroVention/Terumo, CA, USA)
Axium 3D (Medtronic, Irvine, CA, USA)

The insertion speed was set according to the following range of speed: constant speed conditions with changes in speed at 0.1, 0.5, 0.6, 0.8, 1.0, 2.0, and 5.0 mm/s (Table 1).

We have defined as follows for the insertion speed is too fine.

The following insertion speeds were observed (insertion speed = V):

Slow, 0.5 (mm/s) $\geq$ V, Medium, 0.6 (mm/s) $\geq$ V $\geq$ 1.0 (mm/s), High, 1.0 (mm/s) < V

Results

1. Matrix II 360 Standard

The larger coil diameter tends to roll evenly at all speed ranges. This was difficult to achieve with the 10 types of coils that were investigated.

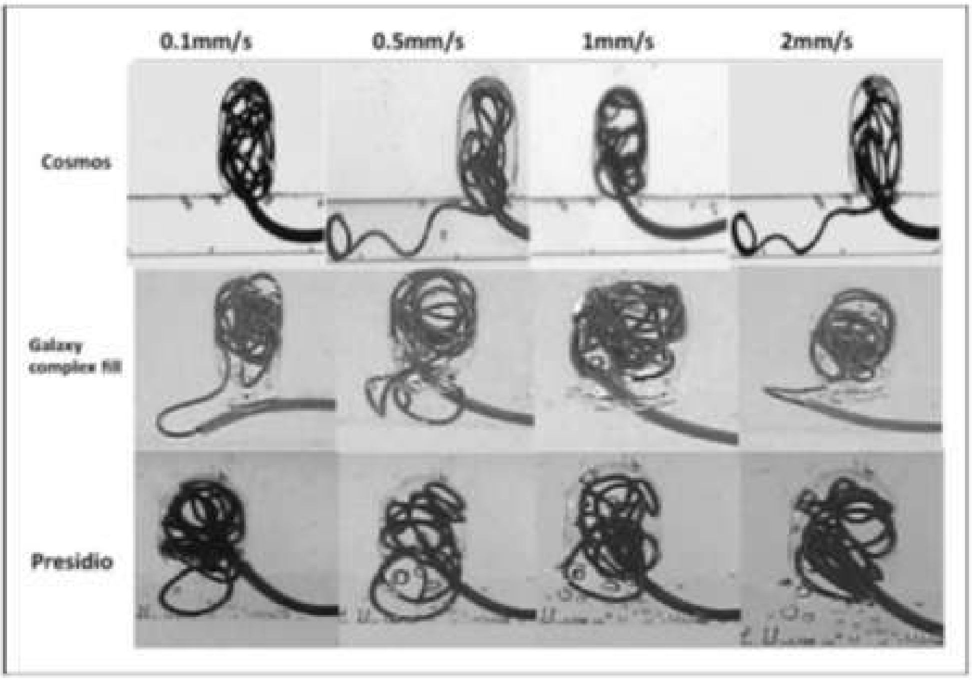

Figure 3. A typical photo of each coil in the present experiment. Axiom 3D coil is a very fine movement. For this reason, the characteristics of the coils, micro catheter-also considered to have changed due ether in motion and stationary status and the like.

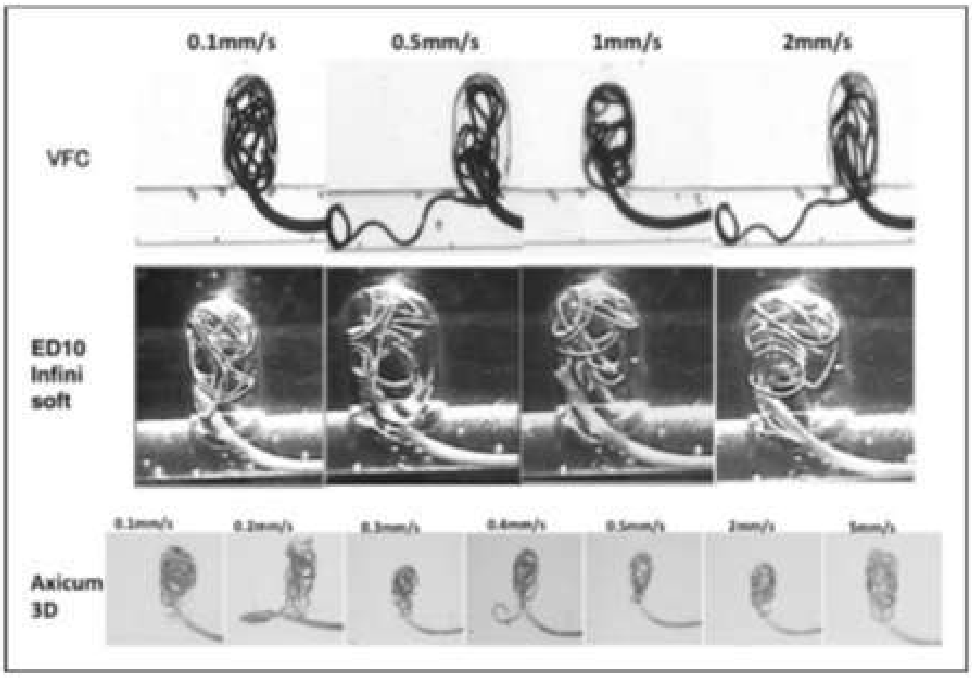

Figure 4. A typical photo of each coil in the present experiment. Axiom 3D coil is a very fine movement. For this reason, the characteristics of the coils, micro catheter-also considered to have changed due ether in motion and stationary status and the like.

2. GDC 360 Standard

There was no coil projecting to the outside of the aneurysm at all speed ranges. The position of the tip loop could be changed to form a compartment portion near the neck coil, which is dense in the upper portion of the dome.

3. GDC 360 Soft

This coil had uniform winding at all speed ranges, especially at medium and high speeds. The tip loop is the second loop subsequent to the coil covering the neck portion, which was stable and covered the inside of the dome.

4. Target 360 Soft

The tip loop section at all speed ranges was located near the neck. It was an easy coil to use in the vicinity of the

Table 1. The winding state of the coil in the aneurysm.

Product	Size (mm diameter × cm long)	Insertion speed (mm/s)									
		0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	2	5
360 Standard	4–7	○	◎	◎	○	○	△	◎	◎	◎	◎
360 Soft	4–8	◎	◎	◎	◎	○	○	○	◎	◎	◎
Matrix 360	4–8	◎	◎	◎	◎	◎	◎	◎	○	○	X
Target 360 soft	4–8	◎	◎	◎	○	◎	◎	◎	◎	○	○
ED10 Infinisoft	16–10	◎	◎	○	○	X	△	△	X	X	○
ED10 Soft	4–8	○	○	○	○	○	○	○	○	○	○
ED14 spiral	4–12	△	△	△	○	○	◎	◎	○	◎	○
Presidio	4–11.5	◎	X	○	X	X	△	△	X	X	X
Galaxy complex fill	4–12	X	△	△	X	X	△	○	△	○	◎
Compass	4–8	○	○	○	△	○	△	X	X	△	X
Cosmos	4–12	X	△	X	○	X	○	○	○	X	◎
Hydro10	4–8	※	※	※	※	※	※	※	○	△	△
VFC	6–10	◎	X	X	△	X	X	X	○	X	X
Axium 3D	4–12	○	X	○	X	◎	◎	◎	○	○	○

◎: Complete dense coiling.
○: Little space formed in the neck side, coil dense embolized in upper portion.
△: The space formed in the neck near part.
X: Coil is projected to parent vessel.
※: Unmeasurable.

neck, but it wound while spreading further to the upper portion of the dome because the second loop had a plated dome center.

5. ED10 Infinisoft

The tip loop covered the neck side at low speed only, and it fell from the second loop in the dome. At middle and high speeds, it protruded from the distal end loop to the main part.

6. ED10 Soft

Only at low speed did the tip loops partly protrude from the neck side to the outside of the aneurysm, and the second loop fit uniformly in the dome. At middle and high speeds, the tip loop remained in the dome center and uniformly wound upward through the central portion of the second loop.

7. ED14 α-spiral

After the second loop coil, at low speed, the neck sides tip loop cover protruded outward in some aneurysms and fit inside the dome. At middle and high speed, the tips in the central aneurysmal dome remained in the second loop of the upper part and evenly rolled.

8. Cosmos

The coil hung over the outside of the aneurysm rather than remaining in the speed area and increased the difference between the dense and odd-shaped loop. Dense and loose coils were easily formed in the compartment.

9. Compass

The upward loop was dense in all speed ranges, and the loops protruded into the main part. Rolling at low speed was good. The last loop protruded outward from the aneurysm and tended to form in the dome above the coil mass at high speed.

10. Hydro Coil

The tip loop coil was easily trapped in the dome. It tended to wind up after the second loop in the dome above the sequentially extruded loop. It fitted inside the dome when high speed began, but the coil was eventually unwilling and the tip loop pushed outside the aneurysm.

11. VFC

VFC had a tendency to have a tip loop at the neck that was hard and fixed. The second loop was not fixed to the neck, with the coil winding from the third loop and extruding from the dome.

12. Galaxy complex fill

At low and middle speeds, the second loop eventually tended to protrude to the outside of the aneurysm. A large compartment with a sparse area became dense in the dome and eventually formed a strong loop.

13. Presidio

The tip loop moved to the neck side in all speed ranges, but the tip loop projected to the main part when it was smaller than the neck portion.

14. Axium 3D

Although there was no protruding into the aneurysm, the outside the loop spread in the middle speed range, and the loop during low speed projected to the main part without winding in the dome. It was harder than a coil of the same size and diameter.

Discussion

Endovascular treatment for cerebral aneurysms has improved rapidly since the approval of Guglielmi detachable coils.[1] A number of new coils with increased resistance to stretch and coil compaction and improved 3D technology are emerging. In recent decades, research and device development have focused on new endovascular treatment methods to occlude the void space of the aneurysm. These methods, some of which are currently in clinical use, use metal, polymeric, or hybrid devices delivered via catheter to the aneurysm site.[2] Balloon assistance and intracranial stents allow more complete coiling of wide neck aneurysms that were previously impossible to treat endovascularly. However, because coil embolization requires an advanced coil insertion technique, analysis of the coils and techniques is required. There is no report of whether such equipment may be inserted during any period of time, yet it is performed. Because coil embolization requires a specific coil insertion method, analysis of the technology is required. Coil insertion during aneurysm treatment, the movement of the coil and catheter, the coil insertion speed, and the force leading to the insertion are not empirically scientific. We performed an objective analysis of this operation and measured coil insertion speed to try to make the procedure safer. For complete embolization, the coil, wire diameter, and material were of different shapes and sizes. To perform optimal coil embolization, it is necessary to understand the shape memory and alloy characteristics of the coil (hardness, shape, and thickness). This experiment examined the optimal insertion rates during clinical use and observed the dynamics of the coil at a constant speed with a fixed catheter position.

Brilstra reported permanent complications of the embolization with controlled detachable coils in 46 of 1256 patients (3.7%; 95% confidence interval (CI), 2.7% to 4.9%) during January 1990 to March 1997; 400 of 744 aneurysms (54%; 95% CI, 50% to 57%) were completely occluded.[3,4] Starke reported that although developments in technology have greatly improved the efficiency and efficacy of treatment of neurovascular disorders, novel devices do not always improve outcomes and may be associated with unique complications. As such, it is paramount to have an in-depth understanding of new devices and the implications of their introduction into clinical practice.[5] Chueh reported that a densely packed aneurysm with a high degree of coil mass uniformity would reduce permeability. Mascitelli described the definition of adequate coil embolization, reduced procedural risk, and stratified patients with residual aneurysms into groups at higher risk and lower risk for recurrence.[6,7] Nagano reported evaluation of the system and the force of the first coil insertion using simulated aneurysms in an in vivo arterial model. The results showed that the insertion force is related to the deployment shape of the coil, that the feedback through the force indicator using sound is very effective, and that the recorder is useful for analysis of the coil embolization. Future experiments involving coil insertion by robots are anticipated.[8]

Placing dense coils with higher mass into the aneurysm is the best way to stop the flow of blood during embolization. Several different coils for this technology have emerged. This experiment presents an effective way of understanding the characteristics of the coils that were objectively observed.

Conclusion

1. Coils used during aneurysm embolization need to wind uniformly within the aneurysm. This is affected by a variety of factors (guiding or micro-catheter position, kick-back phenomenon such as delivery wire, and so forth).
2. Optimal speed and coil design are necessary for insertion of the coil into the aneurysm.
3. It is possible to select the size and design of various coils necessary for different shapes and sizes of aneurysms according to the optimal speed range.
4. Aneurysm wall and coil characteristics are affected by the friction state of the coil (hardness, shape, and thickness), and it is possible to make improvements in the safety of the procedure by performing insertion in the optimum speed range.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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