

Magnetic wires: A novel design for neuroendovascular coil retrieval

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Abstract. The present study aimed to evaluate the operation, application and safety of a novel prototype device designed for the retrieval of a migrated coils, an intraprocedural complication of endovascular aneurysm treatment, compared with the widely used Solitaire AB stent retriever. The prototype retrieval device, referred to as magnetic wires, consisted of two microwires that were joined by a small magnetic ring near to the tips. To retrieve a coil, the wires are advanced through the dislodged coil one at a time and then capture the target coil in a chopstick-like manner, as their tips are attracted to the magnet. *In vitro* tests were performed five times for each retrieval device using a pulsing flow circulator to compare retrieval effectiveness. *In vivo* efficacy testing was performed in 5 male piglets. The left and right carotid arteries were used to assess the magnetic wires and the Solitaire retriever, respectively. While the two devices successfully retrieved coils *in vitro* at a rate of 100%, the magnetic wires did so in a shorter time. *In vivo*, the magnetic wires successfully captured the migrated coils in 3/5 cases (60%), whereas the Solitaire AB stent retriever was successful 4/5 cases (80%). Endothelial injury was observed following magnetic wires retrieval in 1/5 cases (20%) and following use of the Solitaire AB stent retriever in 3/5 cases (60%). These results demonstrate the feasibility and safety of this novel prototype coil retrieval device, which with further development has the potential to be an optimal device for the retrieval of dislodged coils.

Introduction

Cerebral aneurysms are present in an estimated 6% of the global population (1,2). Cerebral aneurysms rupture in 1% of these patients, which, depending on their size, ultimately lead to subarachnoid hemorrhage (3). The 1-year mortality rate was 75% in 6,850 patients with saccular, but untreated ruptured intracranial aneurysms admitted to hospital for a week between 1968 and 2007 in Finland (4). Traditional clipping and emergence coiling are the two necessary treatment measures applied to eliminate cerebral aneurysms (1). The results of the International Subarachnoid Aneurysm Trial (ISAT) (5,6) and the International Study of Unruptured Intracranial Aneurysms (ISUIA) (1) indicated that overall morbidity and mortality of patients after a 1-year follow-up that received endovascular coiling was lower than those that received surgical clipping. The associated complications of coiling have become more common, as it has become a more acceptable method that is used for the majority of patients.

Coil migration is a lethal intraprocedural complication of endovascular aneurysm treatment; however, there is no standard method for managing coil migration (7). Although the majority of physicians administer anticoagulants to address coil migration, certain physicians will use a stent to localize a dislodged coil into a large vessel (8), while others will retrieve coils via surgical or endovascular methods (9). Hopf-Jensen *et al* (10) demonstrated that the Solitaire™ AB Neurovascular Remodeling Device exhibited a number of advantages over other devices for the retrieval of migrated coils, including large cell retriever properties and electrolyte detachment design. These results are similar to those from Liu *et al* (11), who analyzed Trevo Stentriever, which is another frequently used stent. In addition to the inherent stiffness and inconvenience of migrated stents, vessel damage can be caused by stent movement (12).

The present study aimed to develop a novel device for resolving coil migration that was simple to assemble, easy and safe to use, and presented a lower risk to fragile arteries in the brain. The current study designed a novel device, termed magnetic wires, consisting of two microwires, the tips of which were attached with small magnetic rings. A prototype device was constructed from commercially available materials. The feasibility and safety of this device compared with the Solitaire™ AB stent retriever was evaluated *in vitro* and *in vivo*.

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Abbreviations: LM, light microscopy; SEM, scanning electron microscopy; SmCo, samarium cobalt

Key words: neuroendovascular, aneurysm, complications, dislodged coil, retrieval device

Materials and methods

Prototype production and operation. A Mirage™ .008" Hydrophilic Guidewire (Micro Therapeutics, Inc., Irvine, CA, USA) was attached to a small (0.8 mm outside diameter; 0.25 mm inside diameter; 1 mm thickness) samarium cobalt magnetic ring (SmCo; Wanxuan Magnet Company, Shenzheng, China) using ethyl- α -cyanoacrylate glue (Hubei Huitian New Materials Co., Ltd., Shanghai, China). The microwires of the device may be advanced through the dislodged coil one at a time to retrieve the coil via the attraction of the magnetic tips, by forming a loop similar to the configuration of chopsticks (Fig. 1).

In vitro assessment. A Portable FlowTek A-215 Pulsating Flow Circulator (DialAct Corporation, Fremont, CA, USA) was used to compare the prototype with the Solitaire™ AB stent retriever (Medtronic, Minneapolis, MN, USA). The pulsatile pump pushes saline at a rate of 50 cm/sec to simulate arterial blood flow. The insect Axiom™ Detachable Coil (4/8 mm; Medtronic) was inserted into the tube of the circulator through a one-way valve. The corresponding retrieval device was then pushed through the valve to catch the coil. The stent microtube was then sent through, exceeding the coil and the tube was then withdrawn to open the stent (like a net) to catch and retrieve the coil. The coil was then detached and withdrawn by pulling out the push-pole. The method, which uses magnetic wires to retrieve the coil, is described in Fig. 1. For a total of five retrieval trials were conducted for each device. The time from the release to the return of the coil to the tube entrance was recorded.

Animal preparation. All procedures were conducted according to the National Institutes of Health (Bethesda, MA, USA) guidelines (13) for the humane handling of animals and were approved by the Animal Care and Use Committee of The Second Xiangya Hospital of Central South University (Changsha, China). A total of 5 male healthy piglets (age, 2 months; weight, 15-17 kg) were obtained from the Experimental Pig Production Institute (Laboratory Animal Center of PLA General Hospital, Beijing, China). Pigs were housed at a temperature of 18-25°C and a humidity of 40-60%, with a 12 h light/dark cycle. Food was provided twice a day at 2-3% of the pigs' total body weight, with free access to water. General anesthesia was induced using pentobarbital sodium (Merck KGaA, Darmstadt, Germany) (25 mg/kg, intravenously) in 100% oxygen and a 6-F femoral artery sheath was inserted into each animal's right femoral artery following successful Seldinger puncture (14).

Coil release and retrieval. An angiogram was performed after a 6-F guiding catheter (Envoy® Guiding Catheter; Cordis Neurovascular, Inc., Miami, FL, USA) was placed in the proximal carotid artery. The DSA machine can estimate the diameter of vessel, using a metal ball, which may be more accurate. Therefore, the diameter of the carotid artery was measured via angiography using a 1 cm diameter iron ball (Shandong Dongge Steel Ball Group Co., Ltd., Shangdong, China) attached to the right side of the head as a reference. Following the insertion of an Axiom™ Detachable Coil

into the carotid artery, the retrieval procedure was initiated. The coil, which was released into the left and right carotid arteries, was carefully withdrawn using the magnetic wires or the Solitaire™ AB stent retriever as aforementioned (Figs. 2 and 3). The time from coil release to retrieval was recorded for each retrieval system.

All *in vivo* assessments were performed under X-Ray guidance. Using a digital subtraction angiography machine (Innova IGS 530; GE Healthcare, Chicago, IL, USA), the spring coil could be observed. Furthermore, the magnetic micro-conductance wires could be manipulated to pass through the gap of the spring ring under X-ray fluoroscopy, making the magnet end of the micro guidewire connect closely.

Histopathological evaluation of coil retrieval method safety. Following sacrifice of all animals with 20 ml potassium chloride (Jinzhong Development Zone China capital Chemical Technology Co., Ltd., Shaanxi, China; 100 g/l) intravenously, specimens were collected via neck dissection and craniotomy. From the middle portion of the carotid artery, where the retrieval was conducted, two specimens were obtained from each animal. Of these specimens, those for light microscopy (LM) were fixed using 4% formaldehyde solution for 48 h at 22°C. The samples were embedded in paraffin and 4 μ m sections were sliced. Standard histological methods (washing with xylene) were used in order to remove paraffin and the samples were rehydrates with a graduated alcohol series. Masson's trichrome staining was performed using a Masson's trichrome kit (cat. no. ab150686; Abcam, Cambridge, UK) according to the manufacturer's protocol to identify collagen fibers within vessels. Specimens for scanning electron microscopy (SEM) were immersed in 4% paraformaldehyde for 4 h at 22°C, fixed using 1% glutaraldehyde for 2 h at 22°C. They were then dehydrated in a series of graded alcohol, coated with platinum-palladium using an ion coater (cat. no. IB-5; Eiko Engineering Co., Ltd., Hitachinaka, Japan). The tissues were observed using a scanning electron microscope (cat. no. S-2380N; Hitachi, Ltd., Tokyo, Japan). Endothelial lesions presented as defects in the internal elastic lamina via LM and as denudation of the wavy endothelial surface via SEM.

Results

In vitro assessment. The magnetic wires and Solitaire™ AB stent retriever were able to successfully retrieve the coils released *in vitro* (100%; Table I). However, the magnetic wires had a shorter retrieval time compared with the stent retrieval system (Table I).

In vivo assessment. The magnetic wires were successful in 3/5 (60%) of the *in vivo* retrieval trials (Table I). However, the Solitaire™ AB stent retriever successfully captured the migrated coil in 4/5 (80%) of the trials (Table I). There were no incidences of vasospasm or vessel perforation in either group when comparing angiograms prior to and following surgery.

Histopathological safety. Specimens from the right and left carotid arteries, in which the Solitaire™ AB stent retriever and magnetic wires were employed, respectively, were collected from each animal, and processed for LM and SEM.

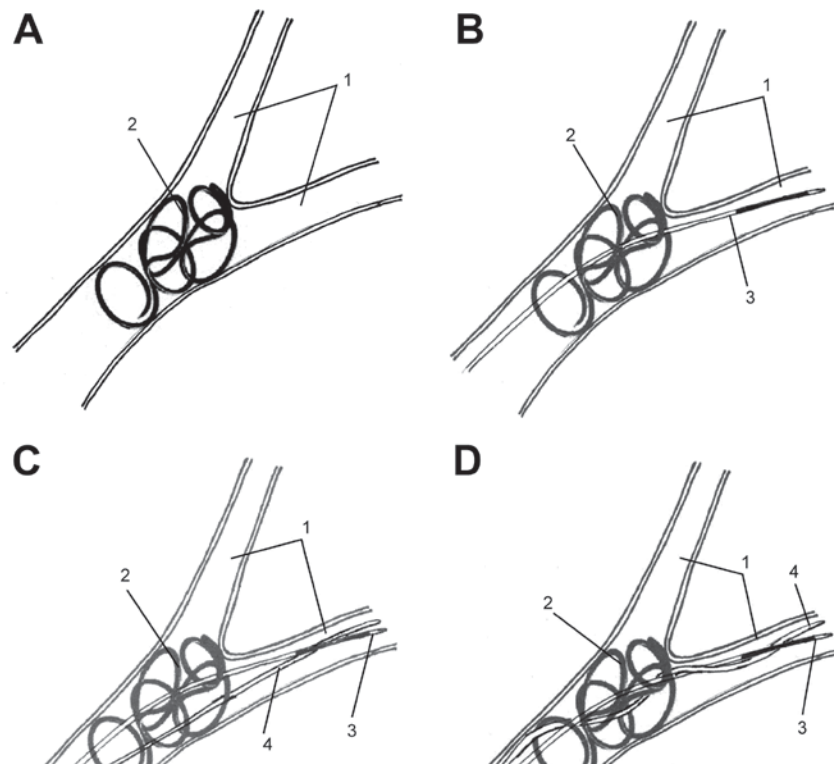


Figure 1. Application of the two-wire magnetic coil retrieval device. (A) A coil dislodged in a blood vessel. (B) Initially, one magnetic microwire is advanced through the coil. (C) The second magnetic microwire is then advanced through the coil. (D) The two wires are twisted such that the tips form a magnetically attractive loop and the coil can be retrieved. 1, Blood vessels; 2, dislodged coil; 3, first microwire; 4, second microwire.

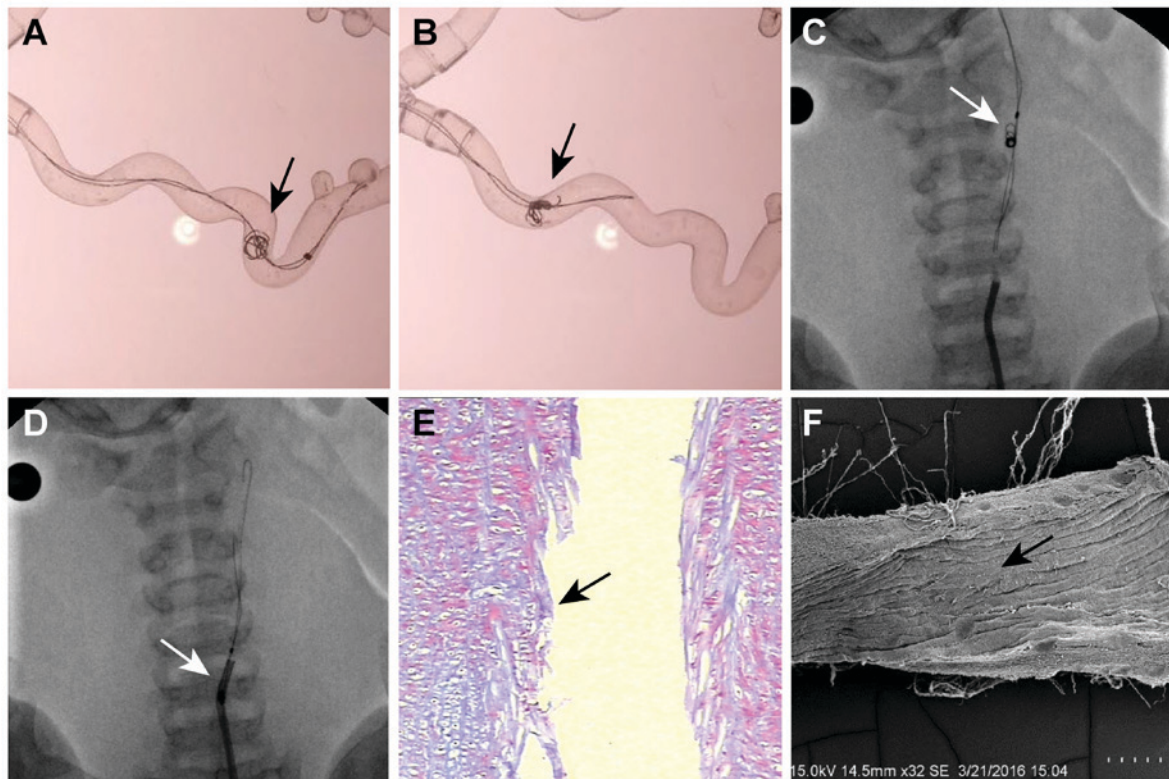


Figure 2. *In vitro* and *in vivo* assessment of the effectiveness and safety of the magnetic wires. (A) *In vitro* assessment, the two magnetic microwires were advanced through the migrated coil (arrow), with their tips attracted to one another by the magnetic rings to form a loop. (B) *In vitro* assessment, the dislodged coil was pulled back to withdraw the magnetic wires as their tips were attracted together through magnetic forces. (C) *In vivo* assessment, under X-Ray guidance the microwires were advanced through the migrated coil (arrow). (D) *In vivo* assessment, the migrated coil (arrow) was retrieved using the two magnetic microwires (X-Ray guidance). (E) Preserved intimal structures (arrow) were observed in specimens from the left carotid artery site (light microscopy; Masson's trichrome stain; magnification, x100). (F) Specimens from the left carotid artery site exhibited normal endothelial structures (arrow) without endothelial damage (scanning electron microscopy; magnification x32,000).

Table I. Coil retrieval time using the magnetic wires and the Solitaire™ AB stent retriever *in vitro* and *in vivo*.

Condition	Device used	Retrieval trial, sec				
		1	2	3	4	5
<i>In vitro</i>	Magnetic wires	228	204	210	189	193
	Solitaire stent	273	235	264	203	221
<i>In vivo</i>	Magnetic wires	Failed	453	436	Failed	415
	Solitaire stent	427	Failed	392	418	387

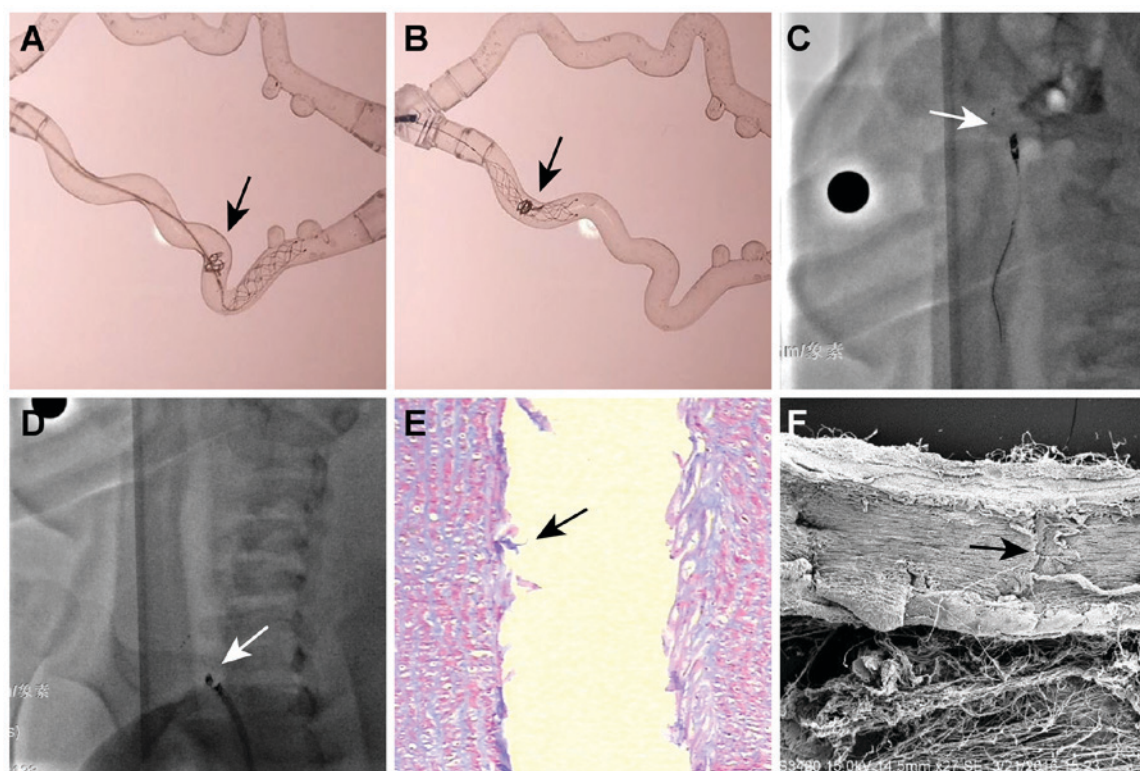


Figure 3. *In vitro* and *in vivo* assessment of the effectiveness and safety of the Solitaire™ AB stent retriever. *In vitro* assessment demonstrated that the Solitaire™ AB stent retriever (A) was advanced through the migrated coil (arrow) and (B) the dislodged coil was pulled back. *In vivo* assessment demonstrated that the Solitaire™ AB stent retriever was also (C) advanced through and (D) retrieved the dislodged coil. (E) Endothelial lesions were detected, which presented as a defect of the endothelial internal elastic lamina (arrow) in specimens from the right carotid artery site (light microscopy; Masson's trichrome stain; magnification, x100). (F) Specimens from the right carotid artery site exhibited injury to the endothelium (arrow) (scanning electron microscopy, magnification, x27,000).

Endothelial lesions were observed in 3 (60%) right carotid arteries (Solitaire™ AB stent retriever) and in 1 (20%) left carotid artery (magnetic wires) (Fig. 3; Table II). There was no gross intimal dissection or any abnormalities beneath the internal elastic lamina in any of the 4 cases in which endothelial lesions were observed via LM. No other specimens indicated any evidence of endothelial injury via either LM or SEM.

Discussion

There have been limited reports of the successful use of various devices for retrieving a coil that has migrated or become misplaced, including the Microsnare (15), a microcatheter retriever (Retriever-10 and Retriever-18), the Alligator

Retrieval Device (9,15), Merci retriever (16), the Solitaire™ AB stent retriever (10) and the Trevo Stentriever device (11,17). Several experts have shaped microwires to capture migrated coils (18,19); however, the majority of clinicians use one of the following four types of coil retrieval devices: Snare, clamps, stents or spiral devices.

Existing coil retrieval devices are mechanically complex, rendering them difficult to manufacture and maneuver. Furthermore, the materials of these devices are too stiff and large for use in the fragile cerebral arteries. Watanabe *et al* (20) described the first use of a loop snare to retrieve a migrated coil during the treatment of a superior cerebellar artery aneurysm. However, since then, there have only been a few reported cases of snares being used to capture dislodged coils (18,21,22); the lack of use of these snares may be due to difficulties in opening

Table II. Detection of EI following the *in vitro* and *in vivo* application of the magnetic wires or the Solitaire™ AB stent retriever.

Animal	Detection method	Retrieval device, presence of EI	
		Magnetic wires	Solitaire stent
1	LM	No	Yes
	SEM	No	Yes
2	LM	No	Yes
	SEM	No	Yes
3	LM	No	No
	SEM	No	No
4	LM	Yes	Yes
	SEM	Yes	Yes
5	LM	No	No
	SEM	No	No

EI, endothelial injury; LM, light microscopy; SEM, scanning electron microscopy.

a snare in small vessels in an appropriate position for coil retrieval. The use of clamps, including the Alligator Retrieval Device, and spiral devices, including Merci, has been reported even less frequently (20,23).

The latest and the most popular type of retrieval device, the stent retrieval system, has a number of marked flaws. The recommended vessel diameter of Solitaire™ AB stent retriever is from 2.2 mm to 6 mm as according to the manufacturer's protocol. Thus, it was considered that if the small artery diameter is <2.2 mm, the stent remains too large; and may consequently push the dislodged coil further into unreachable arterial branches. The movement of the net-like stent within the artery may damage the vessel wall, specifically endothelial cells and the internal elastic lamina, increasing the risk of inflammation and thrombosis (12). The present study also considered that when withdrawing the stent attached to the dislodged coil along the parent artery near the neck of an aneurysm, the coils in the aneurysm may be pulled out by the stent. These potential complications demonstrate that a stent-like device is not the optimal choice for coil retrieval.

The present study aimed to design an alternative type of retrieval device. The original concept of this device originated from a report describing how a number of physicians use two microwires wrapped together to capture dislodged material in a vessel (24). However, this procedure is difficult and is therefore affected by the skills of the clinician. There are a number of similarities between the two-microwire device used in the present study and chopsticks, with magnets being the key feature uniting the two microwires. The magnets used in the present study to produce the prototype device were composed of SmCo; these magnets were produced to power the stepping motor of an electronic watch and their size fits the 0.008' microwires.

In vitro, the prototype device demonstrated the convenience of the wire shape for advancing through the migrated coil and that the attractive force between the two magnets was sufficient for coil retrieval. These findings establish the feasibility of the magnetic wire design. However, the *in vivo* success rate of the novel device, in 3/5 trials, was insufficient. The present study concluded that the lack of interaction with the microwires due to the enlargement of the magnetic ring at the tips resulted in difficulties controlling the device. This impedes the retrieval of a dislodged coil from an area with rapid blood flow. Furthermore, the microwire used in the current study was composed of nitinol, which contains ~51% nickel and thus may be attracted to magnets; this feature of the microwire may therefore interfere with its intended function. In the present study, definite influence was observed when the second magnetic microwire tip reached and caught the former remote end. Future magnetic microwire should therefore not contain ferromagnetic material.

The LM and SEM results demonstrated that the extent of endothelial injury was smaller with the magnetic wire group compared with the Solitaire™ AB stent retriever.

In conclusion, the present study designed a simple novel device that has great potential for the retrieval of dislodged coils during interventional surgery. However, this device requires further development and validation in order to produce an optimal tool for resolving this complication of endovascular aneurysm treatment.

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