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Strategy of stretched Coils: Insights from a single center experience

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A B S T R A C T

Objective: A stretched coil, characterized by excessive elongation within the parent artery during a coil embolization procedure, poses a significant risk of forming a thrombus. This study reports on cases of stretched coils spanning 16 years and discusses effective assessment methods and treatment strategies.

Method: Retrospective analysis of the institutional database comprising 14 cases where stretched coils were observed during coil embolization procedures was conducted, starting from January 2007.

Results: Among the 14 cases, four involved coil embolization for subarachnoid hemorrhage due to ruptured aneurysm, while the remaining cases were unruptured aneurysms. Starting in 2017, vaso-computed tomography (vaso-CT) was employed in nine cases to evaluate the proximal end of the stretched coils.

Reimplantation was performed in 3 cases. Among them, two cases were relieved by pushing the coil delivery wire or microwire, while one case underwent balloon-assisted reimplantation. The stretched coils were removed in three cases by pulling. A rescue gooseneck microsnare technique was applied in one case. The stent was fixed in five cases. In two cases, no additional procedures were performed.

Thrombosis is a potential complication that occurred in three cases of stretched coils.

Conclusion: Many studies have addressed coil stretching and introduced various rescue methods, but relying solely on angiography for diagnosis or applying an inappropriate rescue technique can lead to ischemic stroke. This study emphasized the importance of vaso-CT as a tool for accurately identifying the proximal end of a stretched coil. Additionally, we aimed to facilitate the selection of an appropriate rescue technique.

1. Introduction

Since the mid-1990s, the GDC (the Guglielmi Detachable Coil) has received FDA approval for use in the United States. Many studies have demonstrated the effectiveness of endovascular treatment in managing aneurysms, offering a compelling alternative to clipping. [1–3] Therefore, a notable surge has occurred in the use of coil technology for aneurysm treatment.

Nonetheless, the escalating number of coiling procedures has raised concerns about potential technical complications, including stretched coils,[4] which can lead to serious repercussions, such as thromboembolic vessel occlusion that can result ultimately in a significant ischemic stroke.[5,6] Expertise is needed to retrieve a displaced or stretched coil to prevent major neurological complications.

However, there is a paucity of published material regarding rescue techniques and strategies for managing such complications. These approaches involve snares, balloons, and stent retrievers [7–10].

In this study, we conducted a review of our experience, encompassing 14 consecutive cases where coils were stretched during endovascular treatment. We devised a contemporary treatment algorithm and furnished comprehensive considerations for effectively managing this specific complication.

2. Material and methods

This retrospective study received approval from the institutional review board of our center. All procedures were performed by three experienced neurosurgeons who were certified by the Korean Neuro-Endovascular Society. All patients who undergo aneurysm embolization procedures at our institution are retrospectively entered into the endovascular database. We identified 1,311 patients in this database who had undergone embolization since January 2007. The operative notes for all aneurysm embolization procedures were thoroughly reviewed. A stretched coil was identified during the procedure for all aneurysms included in this series. Exclusion criteria were applied to cases where a migrated coil did not match the stretched coil. The choice of endovascular intervention was based on the surgeon's preference for all patients. Vaso-computed tomography (vaso-CT) has become standard practice since it was introduced to assess stent apposition during the immediate period and to locate accurately the proximal end of a stretched coil.

We determined the appropriate rescue technique based on the stability of the stretched coil, the position of its proximal end, and the

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location of the microcatheter.

A review of the records from the cerebrovascular center at our hospital identified 14 cases of stretched coils during endovascular embolization between December 2008 and November 2023. The clinical and angiographic features were retrospectively assessed from the endovascular records. The data collected included age, sex, presenting symptoms, location, aneurysm profile, primary embolization method, rescue technique, angiographic outcome, complications, and prognosis.

2.1. Endovascular procedures

All endovascular procedures were performed under general anesthesia in a monoplane angiographic suite (before June 2013) or a biplane angiographic suite equipped with three-dimensional rotational angiographic capability (Philips Medical Systems, Best, the Netherlands). Dual antiplatelet therapy was initiated with 75 mg of clopidogrel and 100 mg of aspirin, administered at least 7 days before the procedure for cases of unruptured aneurysms. The day before the procedure, we assessed the antiplatelet function of aspirin and clopidogrel using the VerifyNow Assay (Accumetrics, San Diego, CA, USA). If the cutoff values indicated a poor response, an additional 200 mg dose of cilostazol was administered, or 10 mg of prasugrel was given in place of the clopidogrel.

A 6 Fr guiding catheter (Envoy 6F guiding catheter, Codman Neuro, Raynham, MA, USA) was positioned in the proximal parent artery after accessing the femoral artery up until 2014. After 2014, a long 6F sheath (6F Asahi Fubuki, Asahi, Aichi, Japan, or 6F shuttle, Cook, Bloomington, IN, USA) was employed to guide a 6F intermediate catheter (A Sofia 6F, MicroVention, Tustin, CA, USA) or a Navien 6F (Medtronic, Irvine, CA, USA) as proximal to the aneurysm as possible.

All interventions were carried out under systemic heparinization, with activated coagulation time monitored immediately before the procedure.

Microcatheters are traditionally inserted to treat a superselective catheterized aneurysm. Encountering any form of resistance during coil packing is an indication of a stretched coil. Since 2017, we have used vaso-CT to identify accurately the proximal end of a stretched coil. Protocol used for vaso-CT was as follows. The scanning time was 20 s, and the detector format used was 22 cm × 22 cm. Iodinated contrast medium ((10 mL iohexol 350 mg +90 mL normal saline) was diluted to a concentration of around 10% with a 3 s start delay in order to obtain maximum contrast filling at the level of the target lesion with PSI 300.

3. Results

The average age of the eight male cases and six female cases at presentation was 70 years (range, 35–83 years). Four cases underwent coiling for ruptured aneurysms. The locations of the aneurysms were the anterior communicating artery (A-com) in three cases (21%), the basilar tip, the posterior communicating artery (P-com), the supraclinoid internal carotid artery, and the middle cerebral artery bifurcation (MCAB) in two cases each (14% for each), as well as the anterior choroidal artery (AChA), the vertebral artery, and the middle cerebral artery in one case each (7% for each). (Table 1).

Stent-assisted coil embolization was performed in nine cases (64%) and seven of those cases experienced stretched coils during the jailing technique, while two cases experienced it after employing the through-the-strut technique. Stretched coils occurred during coil embolization in five cases (36%), and one case experienced stretching during the double microcatheter technique.

A 90° microcatheter was used in five cases (36%), a 45° microcatheter in four cases (29%), an S-shaped microcatheter in three cases (21%), and J-shaped and steam-shaped pigtail microcatheters in one case each. Vaso-CT was performed in nine cases (64%).

3.1. Illustrative case with the use of vaso-CT

An 83-year-old woman with an unruptured P-com aneurysm measuring 5.2 mm (neck) × 9.2 mm (width) × 7.1 mm (height) underwent stent-assisted coil embolization. SL-10 pre-shaped 90 microcatheter (Stryker, Fremont, CA, USA) to navigate through the vessel and superselectively position it within the aneurysm sac. Once the microcatheter is inside the aneurysm, a Neuroform Atlas 4.0mm × 21mm stent is deployed across the neck or opening of the aneurysm and conducted serial coil packing (Fig. 1A). During embolization, the tail of the 1.5 mm × 3 cm Target tetra coil herniated after the microcatheter used to select the aneurysm was removed. Although the distal tail of the coil was not displaced, we investigated for potential coil stretching and performed a vaso-CT scan. The vaso-CT revealed evidence of coil stretching, which was not visible on the angiogram. Consequently, we inserted a stent to encompass the stretched portion of the coil (Fig. 1B and C). We employed a bail-out technique of stent retention to achieve fixation of the stretched coil due to the potential risk of tearing the stretched segment, even though coil retrieval was a possible alternative (Fig. 1D).

The stretched coil was completely removed by gentle pulling in three cases (21%, case nos. 3, 7, and 8) without further migration

3.2. Illustrative case with coil removal without any devices

A 46-year-old woman with an unruptured anterior communicating artery (A-com) aneurysm measuring 2.2mm (neck) x 2.7mm (width) x 5.4mm (height) underwent stent-assisted coil embolization. Following the placement of a Neuroform Atlas stent (Stryker, Fremont, CA, US), superselection of the aneurysm was carried out using an SL-10 90-degree microcatheter (Stryker, Fremont, CA, US) through stent strut. During the embolization procedure, there was resistance encountered while delivering a hypersoft helix 2mm x 3cm (MicroVention, Tustin, CA, US). It was gently pulled to remove it. (Fig. 2A and B).

The coil detached and stretched within the delivery microcatheter in two cases (14%, case nos. 9, 10). A delivery wire or microwire was inserted gently to pack and prevent additional migration.

3.3. Illustrative case with stretched coil packing by delivery wire

A 73-year-old woman with an unruptured middle cerebral artery bifurcation (MCAB) aneurysm measuring 2.5mm (neck) x 4.2mm (width) x 2.6mm (height) underwent stent-assisted coil embolization. Catheterization was performed using the SL-10 preshaped S microcatheter (Stryker, Fremont, CA, US), delivering the coil first into the aneurysmal sac and then positioning a Neuroform Atlas stent (Stryker, Fremont, CA, US) across the aneurysm neck. Following hypersoft 3D coil 2.5mm x 6cm (MicroVention, Tustin, CA, US) detachment, the coil tail migrated within the delivery microcatheter, and the coil pusher tip could not make reimplantation of coil. Consequently, a delivery wire was inserted to gently push and complete the coil packing. (Fig. 3A and B).

The detached coil migrated within the parent artery in five cases (36%, case nos. 6, 11, 12, 13, 14), displaying free oscillation or instability, with concerns of potential thrombosis. The rescue method employed involved fixing a stent to secure the coil in place.

3.4. Illustrative case with a complicated stretched coil fixation with a stent

A 68-year-old male with an unruptured MCAB aneurysm measuring 3.4 mm (neck) × 6.3 mm (width) × 2.4 mm (height) underwent stent-assisted coil embolization. Catheterization was performed using the Headway 17 Pre-shaped 45 microcatheter (MicroVention). The coil was delivered initially into the aneurysmal sac, followed by the positioning of an LVIS Jr. stent (MicroVention) across the aneurysm neck. After detaching the 1.5 mm × 3 cm Hypersoft helix (MicroVention), the coil

Table 1
Patient demographics.

No	Sex	Age	Symptoms	Aneurysm size*	Initial plan	Guiding	Streched coil specification				Intraoperative event	Rescue mothod	Post-operative complication	mRS
							Microcatheter	Shape	Streched coil Sequence**	Vaso CT				
1	M	55	SAH	A-com (12/4.5/4)	CE	6F Envoy	SL-10	90	MicroPlex 4/8 (P)	None	Rebleeding	None	Death	6
2	M	75	UIA	Basilar tip (17/9/7.6)	CE	6F Envoy	SL-10	90	GDC18 10/30 (I)	None	Parent artery Occlusion	Retrival- Gooseneck snare	Large infarction	5
3	F	35	SAH	P-com (5.8/3.9/3.5)	CE	6F Envoy	Headliner	pigtail	Axium 3D 1.5/2 (F)	None	None	Removed	None	2
4	F	71	UIA	ICA (9.5/16/10.2)	SAC (Jailing)	6F Shuttle + 6F Navien	SL-10	J	Axium 3D 2/6 (P)	None	None	Observation	None	0
5	M	55	SAH	AchA (5.2/7.5/3.5)	CE	6F Shuttle + 6F Navien	Echelon-10	45	Axium 3D 1/2 (F)	None	None	Ballon assited reimplantation	None	1
6	M	80	UIA	VA (4.4/14.6/18.3)	SAC (Jailing)	6F Shuttle + 6F Navien	Echelon-10	90	Hypersoft Helix 2/3 (P)	Yes	None	Fixation with stent	None	0
7	F	46	UIA	A-com (5.4/2.7/2.2)	SAC (Through)	6F Shuttle + 6F Navien	SL-10	90	Hypersoft Helix 2/3 (F)	Yes	None	Removed	None	0
8	M	63	UIA Pre-mRS 2	Basilar tip (6.4/6.7/5)	SAC (Jailing)	6F Shuttle + 6F Sofia	Sl-10	45	Cosmos 5/15(P)	Yes	None	Removed	None	2
9	F	71	UIA	MCAB (5.3/7.3/5.8)	SAC (Through)	6F Shuttle + 6F Sofia	Headway17	45	Hypersoft helix 3/6 (P)	Yes	None	Reimplantation	None	0
10	F	73	UIA	MCA (2.6/4.2/2.5)	SAC (Jailing)	6F Shuttle + 6F Sofia	SL-10	S	Hypersoft 3D 2.5/6 (P)	Yes	Thrombosis (Tirofiban)	Reimplantation	None	0
11	M	53	SAH	A-com (6.9/5.2/3.8)	CE (DMC)	6F Shuttle + 6F Sofia	SL-10	S	Hypersoft 3D 1/3 (F)	Yes	Thrombosis (bailout stent)	Fixation with stent	Small infarction	1
12	M	68	UIA	MCAB (2.4/6.3/3.4)	SAC (Jailing)	6F Shuttle + 6F Sofia	Headway17	45	Hypersoft Helix 1.5/3 (F)	Yes	None	Fixation with stent	None	0
13	M	67	UIA	ICA (4.5/3.5/2.9)	SAC (Jailing)	6F Shuttle + 6F Sofia	SL-10	S	Hypersoft Helix 1.5/4 (P)	Yes	None	Fixation with stent	None	0
14	F	83	UIA	P-com (7.1/9.2/5.2)	SAC (Jailing)	6F Fubuki + 6F Sofia	SL-10	90	Target tetra 1.5/3 (F)	Yes	None	Fixation with stent	None	0

Size*: neck to dome/width/neck, Sezuence**: initial (I)/packing (P)/final (F), SAH: subarachnoid hemorrhage, UIA: unruptured intracranial aneurysm, A-com: anterior communicating artery, P-com: posterior communicating artery, ICA: internal carotid artery, AchA: anterior choroidal artery, VA: vertebral artery, MCAB: middle cerebral artery bifurcation, MCA: middle cerebral artery, CE: coil embolization, SAC(Jailing): stent assisted coil embolization by jailing technique, SAC(Through): stent assisted coil embolization by through the strut technique, DMC: double microcatheter technique, mRS: modified Rankin score.

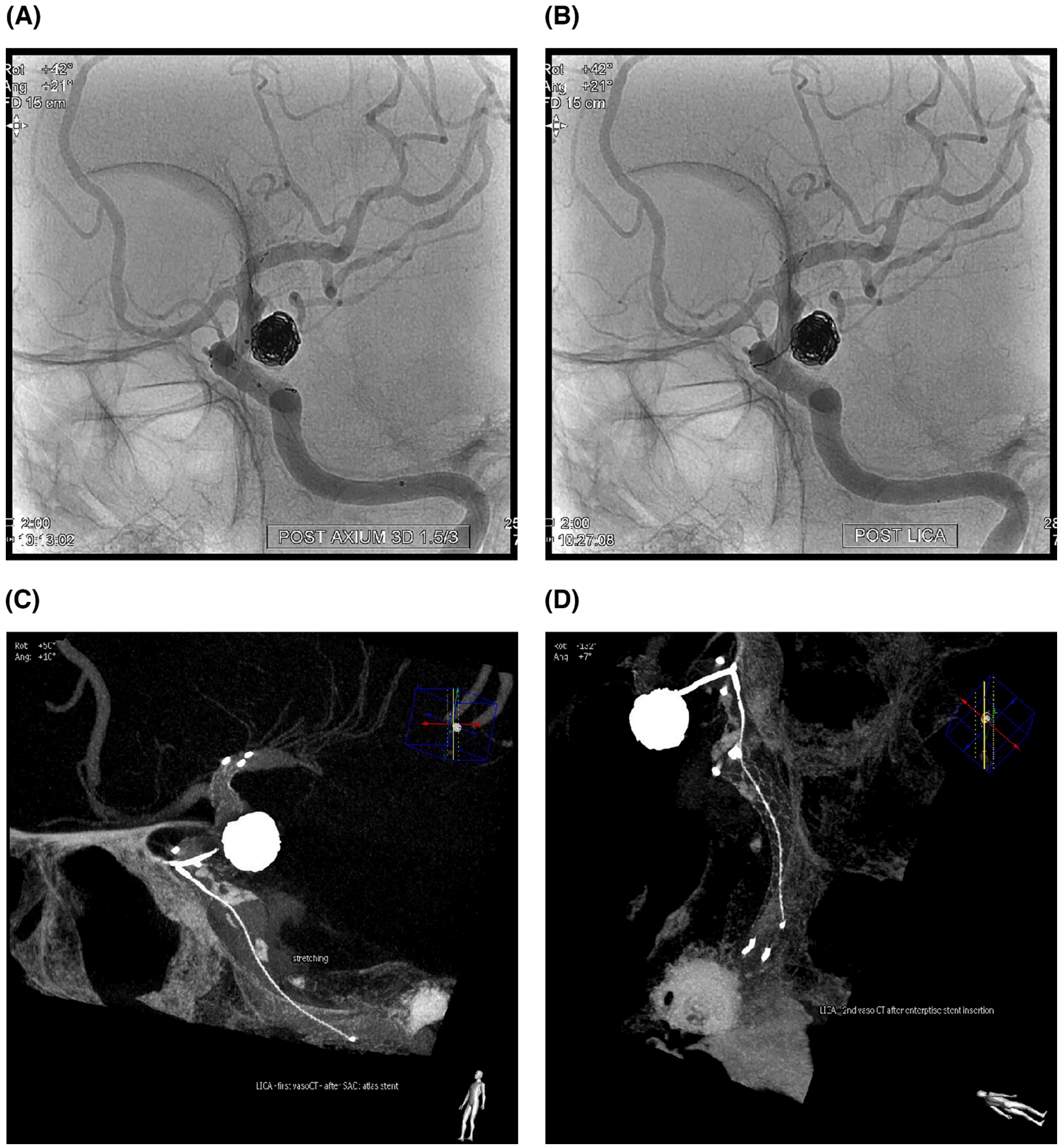

Fig. 1. A case of a stretched coil assessed using vaso-CT: (A) Intra-procedural angiogram showing position of delivery wire. (B)Intra-procedural angiogram showing the stretched coil; the stretched filament segment is not visible on a conventional angiogram. (C) Vaso-CT clearly shows the stretched filament. (D) Vaso-CT shows the fixation of the stretched filament with stent.

tail migrated to the parent artery. Vaso-CT confirmed that the stretched filament had elongated. Attempts were made to retrieve it using a gooseneck microsnare but were unsuccessful. The stretched filament was coiled up to the cavernous segment, and the stretched proximal end was included to allow fixation by deploying an LVIS stent in the cavernous internal carotid artery (ICA) (Fig. 4A and B).

In one case (7%, case no. 5), where the detached coil migrated within the parent artery with concerns of potential thrombosis, a rescue method involving balloon-assisted reimplantation was employed to secure the coil in place.

3.5. Illustrative case of balloon-assisted reimplantation

A 56-year-old male with an unruptured anterior choroidal artery (AChA) aneurysm measuring 3.5mm (neck) x 7.5mm (width) x 5.2mm (height) underwent stent-assisted coil embolization. The catheterization was conducted using the Echelon 10 pre-shaped 45 microcatheter (ev3 Endovascular, Plymouth, MN, USA). The coil was initially delivered into the aneurysmal sac, followed by the positioning of an Enterprise stent (Cordis, Miami, FL, US) across the aneurysm neck. After the detachment of an Axium 3D coil measuring 1mm x 2cm (ev3, Plymouth, Minnesota, US), the coil tail migrated into the parent artery. Since the stretched coil length was relatively small, we were able to insert the migrated stretched coil back into the aneurysm by inflating a micro balloon at the entrance of the aneurysm. (Fig. 5A and B).

The coil was retrieved in one case (7%, case no. 2) using a gooseneck microsnare.

3.6. Illustrative case of retrieval by gooseneck micro snare

A 76-year-old male with a ruptured basilar tip aneurysm measuring 7.6mm (neck) x 9.7mm (width) x 17mm (height) underwent coil embolization. The aneurysm was catheterized using an SL-10 preshaped 90 microcatheter (Stryker, Fremont, CA, US). A GDC 18-fibered VortX Shape Coil measuring 10mm x 30cm was initially delivered into the aneurysmal sac. However, during the advancement of the coil, further

Fig. 2. A case of stretched coil removed by gentle pull: Photograph of the removed stretched coil.

progress was impeded by resistance. It was determined that a stretched coil had formed at the proximal portion of the coil. To address this, a 2-mm GooseNeck microsnare (Microvena, WhiteBear Lake, MN, US) was introduced. The snare catheter within the kit was utilized effectively, resulting in the successful retrieval of the stretched coil. (Fig. 6A and B).

A stretched coil occurred in one case (7%, case no. 4) during stent-assisted coil embolization using the jailing technique. While most of the elongated portion was confined by the stent, the proximal end that was not jailed was observed. However, the migrated proximal end of the stretched coil did not show any signs of floating or instability within the patent artery. This allowed the procedure to be concluded without the need for a rescue technique. (Fig. 7).

Perioperative rebleeding occurred in one case (7%, case no. 1) during manipulation of the microcatheter with a stretched coil. Due to severe vasospasms and unstable vital signs, the stretched coil could not be removed, and the procedure was terminated. The patient passed away 1 day later.

Three cases (21%, case nos. 2, 10, 11) experienced parent or major vessel occlusion. Occlusion of the superior cerebellar artery occurred in case no. 2, resulting in discharge with a mRS score of 5. Case no. 10 achieved full recanalization after tirofiban was administered and the patient was discharged with a mRS score of 0. A stretched coil migrated from the A-com aneurysm to the MCA in case no. 11, leading to partial occlusion and thrombosis in the anterior cerebral artery (ACA). Tirofiban was administered and intracranial stenting was performed in the ACA and MCA, resulting in recanalization and fixation of the stretched coil. (Fig. 8).

4. Discussion

The detachable coil system used to treat intracranial aneurysms consists of a device positioning unit (DPU) that delivers a detachable coil to the aneurysm. The microcoil is connected within the DPU. The microcoil is typically constructed with an extremely thin platinum wire, wound tightly around a cylindrical or multi-dimensional thin core called the mandrel, forming a rigid spiral known as the primary wind [11]. Additionally, the coil is wound into a spiral or three-dimensional shape to create individual loops, thereby forming the coil diameter.

The delivery wire, which is a component of the detachable coil system, serves to push the coil into its target location. Depending on the manufacturer, it also plays a role in allowing current flow to detach the coil. Additionally, the distal end of the delivery wire may have markings to facilitate movement of the coil to the proximal end of the microcatheter without the need for fluoroscopy, or the distal end may be marked with radiopaque markers for alignment before detaching the coil. Detachable coils employ various detachment mechanisms depending on the manufacturer. They employ mechanical, hydraulic, or electrical detachment methods using a detachment device.

A phenomenon called "stretch" may occur during coil embolization for an intracranial aneurysm, where the primary wind of the coil becomes loose. Coil manufacturers are making significant efforts to enhance the stretch resistance of the coils. One prominent method to improve the stretch resistance of coils involves using polypropylene or polyglycolic acid strands within the central core of the primary wind [12].

However, the stretched coil mechanism remains controversial. Abe et al. explained that stretching occurs due to fatigue or failure of the

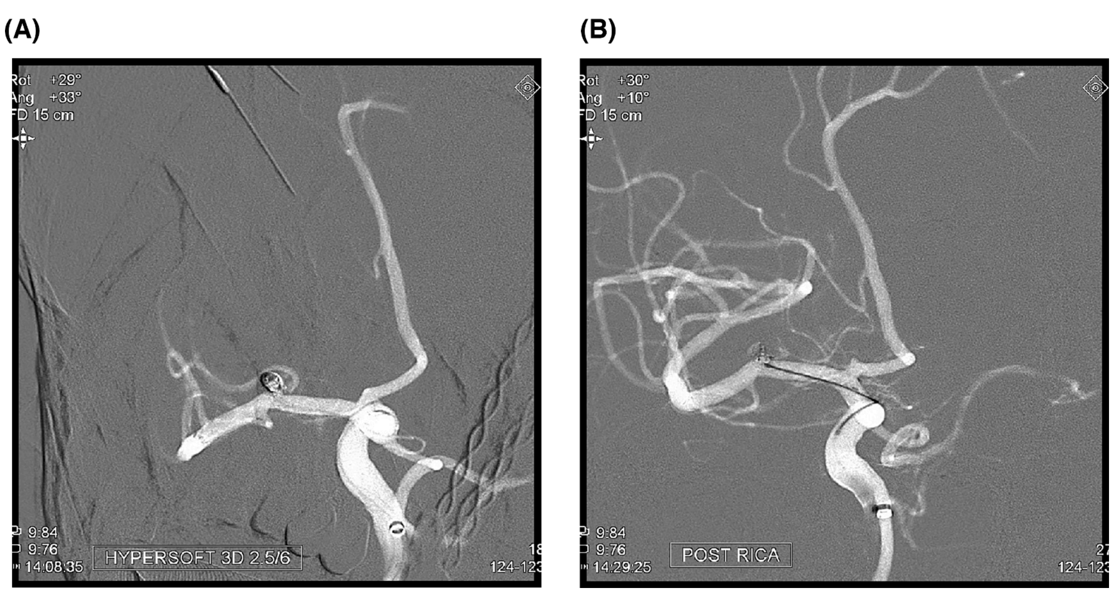

Fig. 3. A case of stretched coil reimplantation by microwire: (A) Intra-procedural angiogram showing the stretched coil in delivery microcatheter. (B) Intra-procedural angiogram showing the microwire place stretched coil into sac.

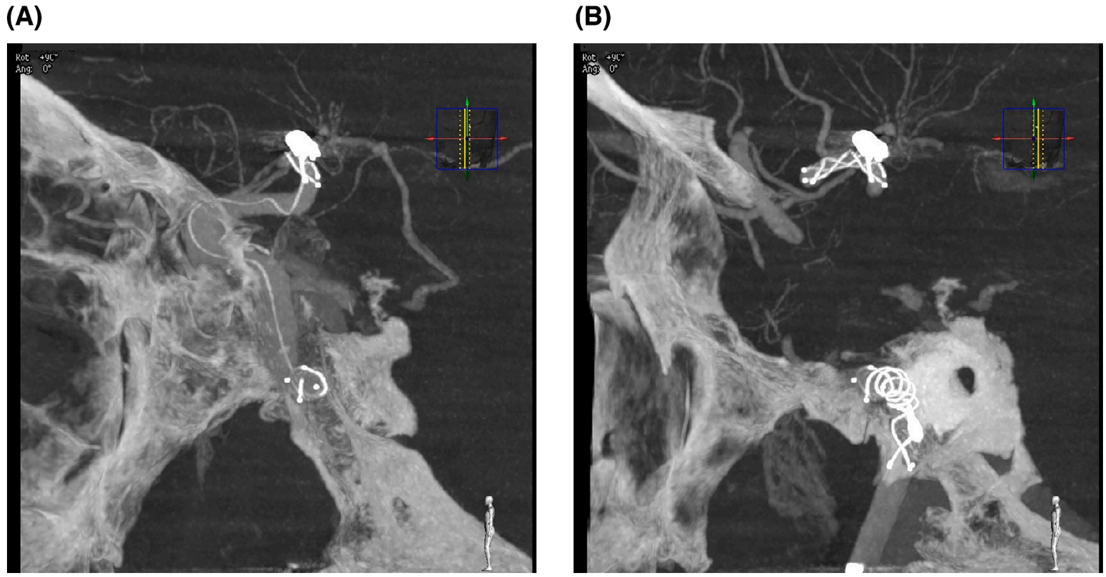

Fig. 4. A case of a stretched coil fixed with a stent: (A) Vaso-CT showing elongation of the stretched coil filament. (B) Vaso-CT showing complete fixation of the proximal end of a stretched coil with an LVIS stent.

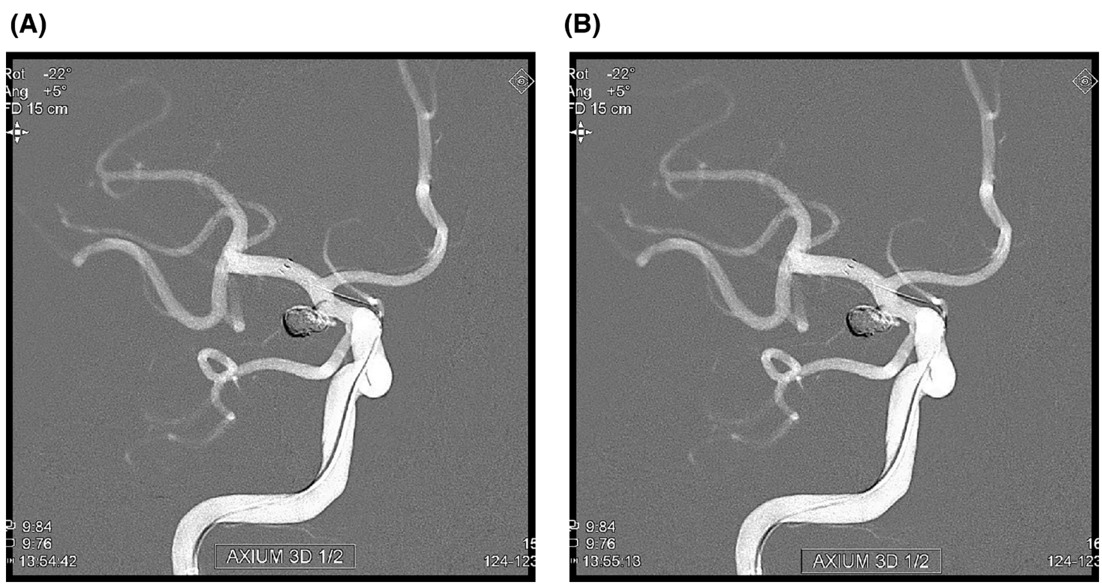

Fig. 5. A case of balloon reimplantation: (A) Intra-procedural angiogram showing the stretched coil before micro balloon inflation (B) Intra-procedural angiogram showing the place stretched coil into sac after deflation of micro balloon.

primary coil. As a result, the coil can be easily stretched into an initially super-thin core wire, which may fracture [13]. Abdelrady et al. reported that the stretching process begins at the level of the secondary coil configuration when excessive force is applied to the coil terminus. The terminus can occasionally entangle with the existing coil mesh, resulting in significant elongation of the coil without disrupting its composition. Further manipulation by the operator perpetuates the stretching of the coil, which may continue for several meters until it regains its original form as a very thin wire [10]. In our cases various small sized coils were stretched. Small coils, in particular, are frequently used to enhance packing density within an aneurysm. During the placement of coils within an aneurysm, if there is any noticeable movement or shifting of the coils, it may suggest the possibility of coil stretching. When coils are introduced into an aneurysm, specific shaping and protective measures are typically employed, and these measures can potentially result in alterations to the coil's length or configuration. Therefore, it is crucial to exercise caution when observing any coil movement within an aneurysm during the placement procedure, as it may indicate the occurrence of stretching or changes in coil length. Furthermore, if the coil is completely detached, herniation of the intrasaccular coil should not occur, regardless of whether it's stretched. This suggests that issues related to the detachment system, including potential manufacturer-related problems, cannot be ruled out.

Therefore, addressing such stretched coils is crucial not only during an interventional procedure for coil packing within the aneurysm but also due to the potentially serious repercussions of having the proximal end of a stretched coil positioned unstably within the parent artery. This instability can lead to severe consequences, such as thromboembolic vessel occlusion.

In cases where coil displacement is evident on angiography, it can be challenging to differentiate between stretching and fractures or migration, as emphasized by Liu et al. [14] If complications, such as coil

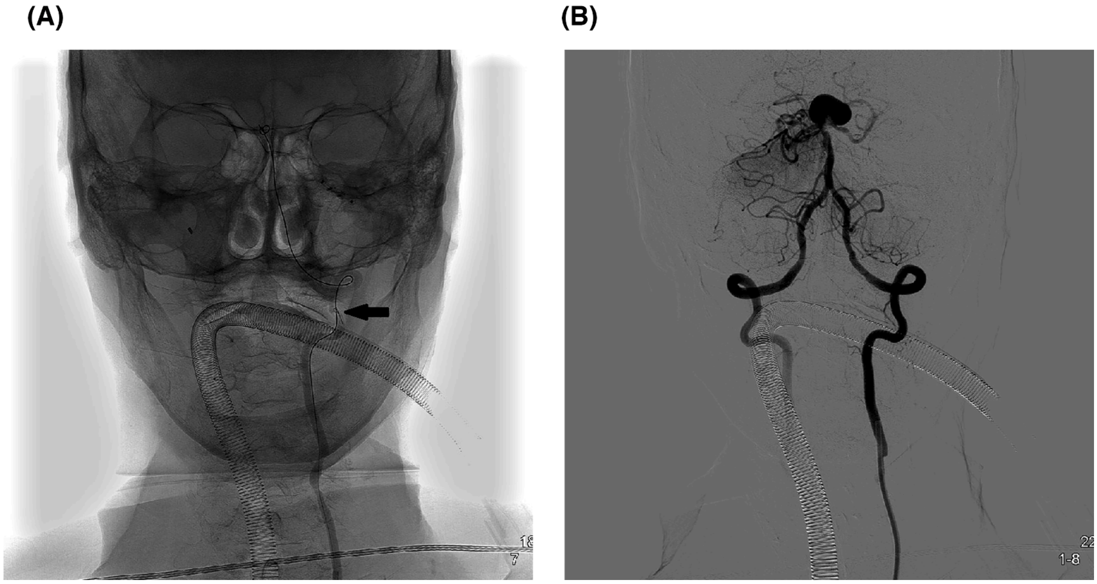

Fig. 6. A case of snaring: (A) Intra-procedural angiogram and radiography showing gooseneck micro snare at V3 segment with stretched coil (B) Intra-procedural angiogram showing the complete retrieval of stretched coil.

Fig. 7. Intra-procedural angiogram stretched coil without instability including oscillation.

migration or fracture occur, they can be addressed through retrieval methods, including the migrated portion or fixation with a stent on conventional angiography [4,15]. In contrast, stretched coils, which may not be visible on conventional angiography, pose a higher risk of thrombosis if the entire segment of the stretched filament is not treated. Additionally, if the end of a stretched coil is obscured by bony structures or other factors, it may remain undetected during the procedure.

The introduction of the flat-detector C-arm cone-beam computed tomography technology (vaso-CT) has enabled intraoperative cross-sectional imaging with CT-like quality [16]. This advancement has not only improved assessments of wall apposition for flow diverter stents and general intracranial stents but also allows for differentiation of the nitinol component in nitinol stents [17,18].

The diameter of the primary wind of intracranial coil measured within the range of approximately 0.00175 to 0.003 in. (44.45 μm to 76.2 μm). Additionally, a single wire used for a pipeline stent has a smaller size, approximately 0.00118 in. (30 μm), making it useful for visualizing in vaso-CT scans. Given these advantages, we decided to use vaso-CT when a stretched coil is suspected to have occurred [19,20].

The higher spatial resolution along with a wide range of contrast provides a clearer visualization of a stretched coil than conventional angiography. The development of metal artifact reduction technology has been beneficial for detecting stretched coils [21]. We conducted a literature review of the PubMed and Google Scholar databases. Until now, no study has specifically compared the effectiveness of detecting stretched coils between vaso-CT and conventional angiography. The present study is the first to describe the utility of vaso-CT for assessing stretched coils.

We developed the following algorithm using vaso-CT, based on the presence or absence of the proximal end of the stretched coil inside the delivery microcatheter and the location of the stretched filament if it is outside (Fig. 9).

If the proximal end of the stretched coil is detected within the microcatheter on vaso-CT, as described by Sugiu et al., then the stretched coil is still controllable and reversible. Various methods, such as gentle pushing, pulling, or using micro-balloons, can be used to pack or remove the coil if it stays within the microcatheter. If these attempts are unsuccessful, other rescue methods should be considered [22].

When the proximal end of a stretched coil is positioned out of the microcatheter and located in the parent artery, the stability of the proximal end plays a crucial role in selecting the rescue method. If the proximal end is unstable, there is a higher risk of thrombosis, making it imperative to proceed with a rescue method. Priority is given to the retrieval method. While various retrieval methods have been introduced in several studies, one approach involves using guidewires [23]. Retrieving stretched coils using a snare device have also been introduced [6,24]. Recent advancements in mechanical thrombectomy have popularized stent-assisted retrieval techniques, which, when combined with aspiration, enhance the success rate of stretched coil retrieval [25,26]. It is important to consider the effect on the stability of an already packed coil when retrieving a stretched coil. If the proximal end of the stretched coil cannot be retrieved and it migrates distally, fixation with a stent should be considered to secure it in place [15]. Another option is to wait for neoendothelialization to occur if the proximal end of the stretched coil is stable and there is a low risk of thrombosis [27]. Additionally, microsurgery can be used to remove the stretched coil, but the benefit is controversisl [14].

When the proximal end of the stretched coil is located outside of the

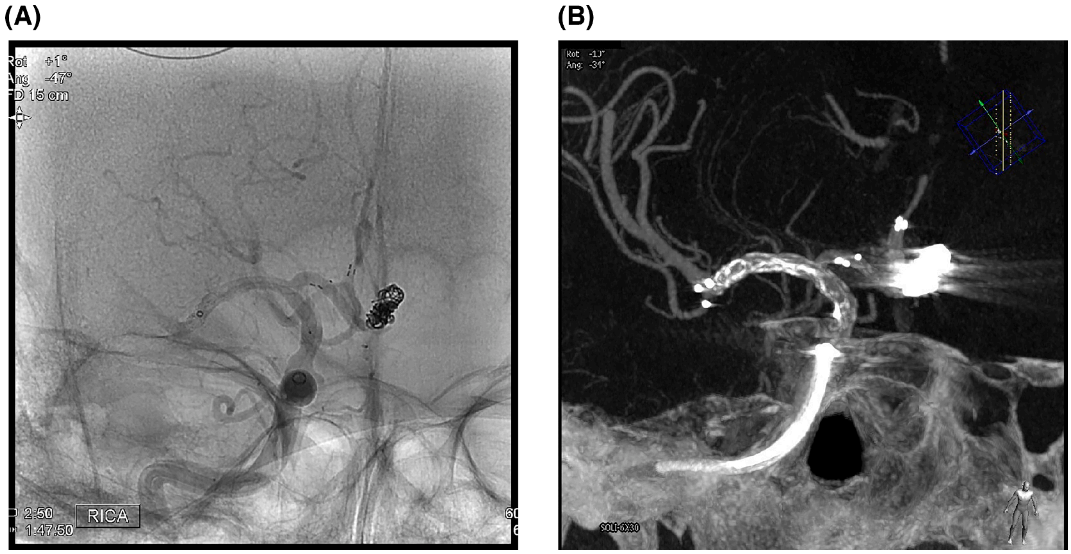

Fig. 8. Stretched coil filament migrated to the middle cerebral artery (MCA) during coiling of the anterior communicating artery (A-com): (A) Intra-procedural angiogram displaying partial stenosis of the anterior cerebral artery (ACA) and the stretched coil filament located at the MCA, as well as the internal carotid artery (ICA). (B) Vaso-CT image demonstrating the successful and complete fixation of the stretched coil within the stent.

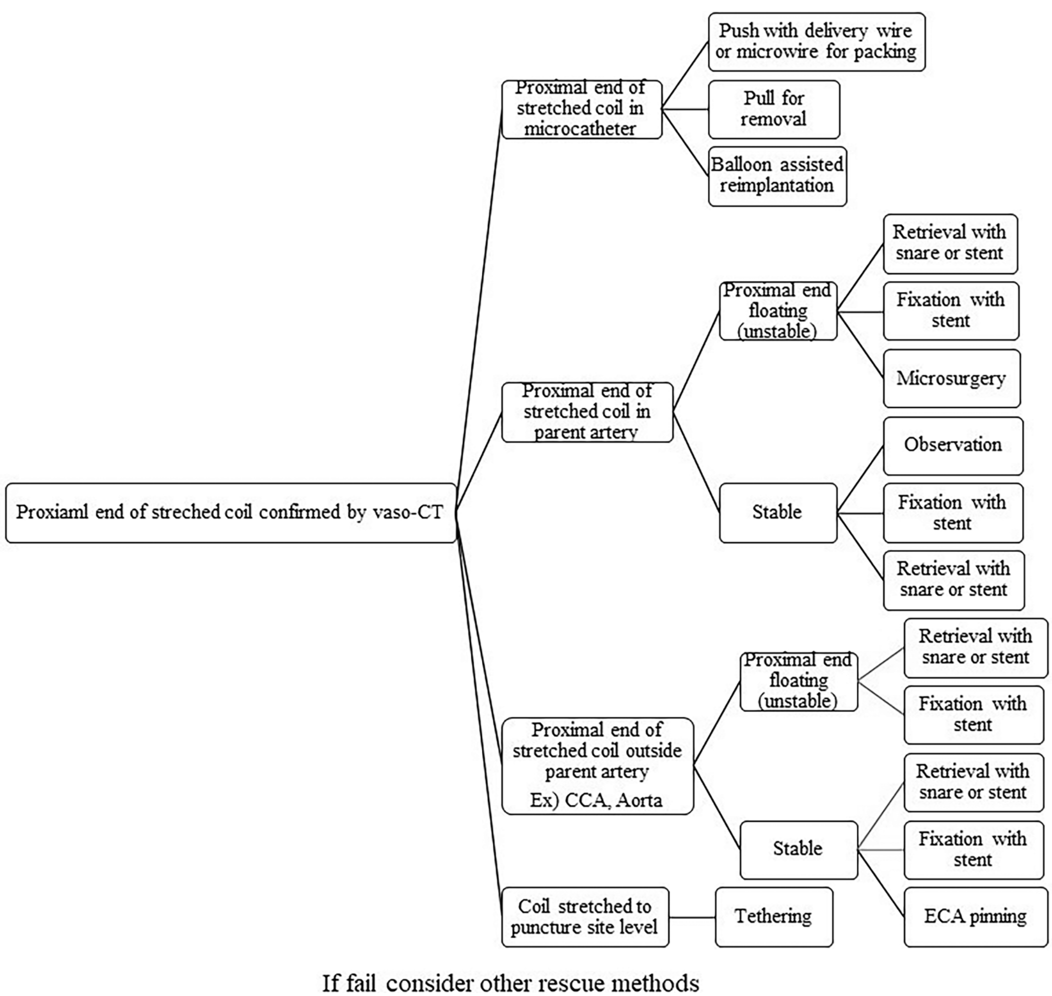

Fig. 9. Strategy of a stretched coil based on location of the proximal end. CCA: common carotid artery.

microcatheter and parent artery, such as the aorta or common carotid artery, the stability of the proximal end remains crucial in selecting a rescue method. If the proximal end is freely floating, retrieval can be achieved using a snare or stent [28]. Additionally, if the stretched proximal end is located in the aorta, it can be advanced up to the common carotid artery and fixed with a carotid stent. If the proximal end is stable, a snare or stent can be used for retrieval, or a stent can be used for fixation [29].

When the stretched coil extends up to the puncture site, the risk of thrombosis is low, and tethering becomes a potential option [15].

Overall, choosing the appropriate rescue method depends on the specific situation and the location of the stretched coil's proximal end.

5. Conclusion

Many studies have explored coil stretching and introduced rescue methods. However, relying solely on angiography for diagnosis and applying an inappropriate rescue technique can lead to ischemic stroke. This study emphasizes the utility of vaso-CT in locating the proximal end of a stretched coil. Furthermore, this study provides treatment options based on the location of the proximal end of a stretched coil.

CRediT authorship contribution statement

Jun Ho Shim: . **Jong-Hyun Park:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Gi Yong Yun:** . **Jae-Min Ahn:** Investigation. **Hyuk-Jin Oh:** Investigation. **Jai-Joon Shim:** Methodology, Investigation. **Seok Mann Yoon:** .

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data is available from the corresponding author on reasonable request.

Declarations

Ethics approval This study was in accordance with the ethical standards of the Institutional Review Board of our hospital and with the tenets of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate Not applicable.

References

[1] Vinuela F, Duckwiler G, Mawad M. Guglielmi detachable coil embolization of acute intracranial aneurysm: perioperative anatomical and clinical outcome in 403 patients. J Neurosurg 1997;86:475–82.
[2] Byrne JV, Sohn MJ, Molyneux AJ, Chir B. Five-year experience in using coil embolization for ruptured intracranial aneurysms: outcomes and incidence of late rebleeding. J Neurosurg 1999;90:656–63.
[3] Molyneux AJ, Kerr RS, Yu LM, Clarke M, Sneade M, Yarnold JA, et al. International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. Lancet 2005;366:809–17.
[4] Leslie-Mazwi TM, Heddier M, Nordmeyer H, Stauder M, Velasco A, Mosimann PJ, et al. Stent retriever use for retrieval of displaced microcoils: a consecutive case series. AJNR Am J Neuroradiol 2013;34:1996–9.
[5] White PM, Lewis SC, Nahser H, Sellar RJ, Goddard T, Gholkar A, et al. HydroCoil Endovascular Aneurysm Occlusion and Packing Study (HELPS trial): procedural safety and operator-assessed efficacy results. AJNR Am J Neuroradiol 2008;29: 217–23.
[6] Lee CY. Use of wire as a snare for endovascular retrieval of displaced or stretched coils: rescue from a technical complication. Neuroradiology 2011;53:31–5.
[7] Cho JH. Endovascular rescue method for undesirably stretched coil. J Korean Neurosurg Soc 2014;56:364–7.
[8] Hopf-Jensen S, Hensler HM, Preiss M, Muller-Hulsbeck S. Solitaire(R) stent for endovascular coil retrieval. J Clin Neurosci 2013;20:884–6.
[9] Stidd DA, Johnson AK, Lopes DK. Manual Aspiration Technique to Retrieve a Prematurely Detached Coil during Cerebral Aneurysm Embolization. Neurointervention 2014;9:21–5.
[10] Abdelrady MM, Ognard J, Abdelsamad AM, Mahmoud M. Parent artery stenting as a rescue management for stretched coils during cerebral aneurysms embolization: Report of three cases and review of literature. Interv Neuroradiol 2022;28:613–22.
[11] Linfante I, Akkawi NM, Perlow A, Andreone V, Wakhloo AK. Polyglycolide/ polylactide-coated platinum coils for patients with ruptured and unruptured cerebral aneurysms: a single-center experience. Stroke 2005;36:1948–53.
[12] Hui FK, Fiorella D, Masaryk TJ, Rasmussen PA, Dion JE. A history of detachable coils: 1987–2012. J Neurointerv Surg 2014;6:134–8.
[13] Abe T, Hirohata M, Tanaka N, Uchiyama Y, Morimitsu H, Kojima K, et al. Coil migration, malposition, stretching and retrieval. Interv Neuroradiol 2000;6(Suppl 1):143–7.
[14] Ding D, Liu KC. Management strategies for intraprocedural coil migration during endovascular treatment of intracranial aneurysms. J Neurointerv Surg 2014;6: 428–31.
[15] Schutz A, Solymosi L, Vince GH, Bendszus M. Proximal stent fixation of fractured coils: technical note. Neuroradiology 2005;47:874–8.
[16] Caroff J, Mihalea C, Neki H, Ruijters D, Ikka L, Benachour N, et al. Role of C-arm VasoCT in the use of endovascular WEB flow disruption in intracranial aneurysm treatment. AJNR Am J Neuroradiol 2014;35:1353–7.
[17] Mewissen MW. Self-expanding nitinol stents in the femoropopliteal segment: technique and mid-term results. Tech Vasc Interv Radiol 2004;7:2–5.
[18] Tsuruta W, Matsumaru Y, Hamada Y, Hayakawa M, Kamiya Y. Analysis of closed-cell intracranial stent characteristics using cone-beam computed tomography with contrast material. Neurol Med Chir (Tokyo) 2013;53:403–8.
[19] Fischer S, Vajda Z, Aguilar Perez M, Schmid E, Hopf N, Bazner H, et al. Pipeline embolization device (PED) for neurovascular reconstruction: initial experience in the treatment of 101 intracranial aneurysms and dissections. Neuroradiology 2012; 54:369–82.
[20] White JB, Ken CG, Cloft HJ, Kallmes DF. Coils in a nutshell: a review of coil physical properties. AJNR Am J Neuroradiol 2008;29:1242–6.
[21] Chintalapani G, Chinnadurai P, Srinivasan V, Chen SR, Shaltoni H, Morsi H, et al. Evaluation of C-arm CT metal artifact reduction algorithm during intra-aneurysmal coil embolization: Assessment of brain parenchyma, stents and flow-diverters. Eur J Radiol 2016;85:1312–21.
[22] Sugiu K, Martin JB, Jean B, Rufenacht DA. Rescue balloon procedure for an emergency situation during coil embolization for cerebral aneurysms. Technical note J Neurosurg 2002;96:373–6.
[23] 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 1994;35:994–8. discussion 9.
[24] Fiorella D, Albuquerque FC, Deshmukh VR, McDougall CG. Monorail snare technique for the recovery of stretched platinum coils: technical case report. Neurosurgery 2005;57:E210;. discussion E.
[25] O'Hare AM, Rogopoulos AM, Stracke PC, Chapot RG. Retrieval of displaced coil using a Solitaire((R)) stent. Clin Neuroradiol 2010;20:251–4.
[26] Mendez-Ruiz A, Mendez AA, Zevallos CB, Quispe Orozco D, Farooqui M, Samaniego EA, et al. Retrieval of distally migrated coil using stent retriever and proximal aspiration. J Neurointerv Surg 2021;13:860.
[27] Fukawa N, Ueda T, Ogoshi T, Kitazawa Y, Takahashi J. Vascular endothelial repair and the influence of circulating antiplatelet drugs in a carotid coil model. J Cent Nerv Syst Dis 2021;13. 11795735211011786.
[28] Pride Jr GL, Horowitz MB, Purdy PD. Endovascular problem solving with intravascular stents. AJNR Am J Neuroradiol 2000;21:532–40.
[29] Wang C, Xie X. Treatment of an unraveled intracerebral coil. Catheter Cardiovasc Interv 2010;76:746–50.