Stretched and fractured Neuroform Atlas® stent during a stent-assisted coil embolization: A case report

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Abstract. The Neuroform Atlas® stent is one of the most recently developed stents for coil embolization, with advancements in a lower-profile delivery system, enhanced trackability, smaller cell size, and increased wall conformability. Because of these advantages, the Neuroform Atlas® stent shows high technical success with few procedure-related complications. However, the present study reported a rare complication of a stretched and partially fractured Neuroform Atlas® stent due to unexpected partial withdrawal of microcatheter during deployment for coil embolization of an intracranial aneurysm. The measured length of the stent was ~30 mm, which was greater than the normal length (21 mm). An additional stent was inserted into the distal part of the deployed stent to stabilize the damaged stent and remodel the aneurysm neck. This complication was considered to potentially result from the combination of several factors, including: Curved vessel; open-cell stent; unexpected microcatheter withdrawal during stent deployment; and hooking of the aneurysm selecting microcatheter with stent strut. Understanding the stent design and careful manipulation while avoiding unexpected withdrawal of the microcatheter could prevent this complication.

Introduction

The advancement of technology has led to the development of various new stents for intracranial aneurysms (IA) treatment. The Neuroform Atlas® stent (Stryker Neurovascular, Fremont, CA, USA) is one of the most recently developed laser-cut stents with an open-cell strut, and it is the successor of the Neuroform EZ® stent (Stryker Neurovascular). Compared with its former generation, it has the significant improvements of a lower-profile delivery system via a 0.42-mm or 0.43-mm inner diameter microcatheter, enhanced trackability, smaller cell size, and increased conformability to vessel walls (1). Recently published prospective trials showed the efficacy and safety of Neuroform Atlas® stents in treating IA with an excellent rate of procedure success and acceptable procedure-related complications (2-4). Among the procedural difficulties, several cases have been reported where stent migration or stent deployment in unexpected landing sites occurred during the procedure (2,5-14). Fracture and deformation of intracranial stents have rarely been reported. The authors report a stretched and partially fractured Neuroform Atlas® stent due to unexpected partial withdrawal of the stent-engaged microcatheter during deployment for coil embolization of an unruptured intracranial aneurysm.

Case report

A 42-year-old female patient had been diagnosed with an unruptured IA at the paraclinoid segment of the left internal carotid artery (ICA) on magnetic resonance angiography (MRA) after her health check-up. She had no neurological symptoms and signs without a history of underlying disease or smoking. On digital subtraction angiography, the location of the IA was the left superior hypophyseal artery with a posterior-medial direction. The sizes of the IA were 4.7 mm in maximal diameter and 2.4 mm in neck diameter. She had undergone coil embolization for the IA on April 2015. During five years of the follow-up period, we detected the major recurrence of the IA on MRA and digital subtraction angiography (Fig. 1). Because the surgical access and aneurysm exposure for aneurysm clipping was not easy, we decided to perform a second coil embolization for the recurred IA using the stent-assisted catheter jailing technique due to the wide-necked aneurysm, the angle of the parent artery curvature, and to prevent recurrence.

The endovascular procedure was performed under general anesthesia using a biplane digital subtraction angiography suite (Artis Q, Siemens Healthineers AG, Erlangen, Germany). Aspirin (100 mg/day) and clopidogrel (75 mg/day) were administered for 14 days before treatment. Anticoagulation using intravenous heparinization was used to maintain an activated clotting time of 250-300 sec during the procedure.

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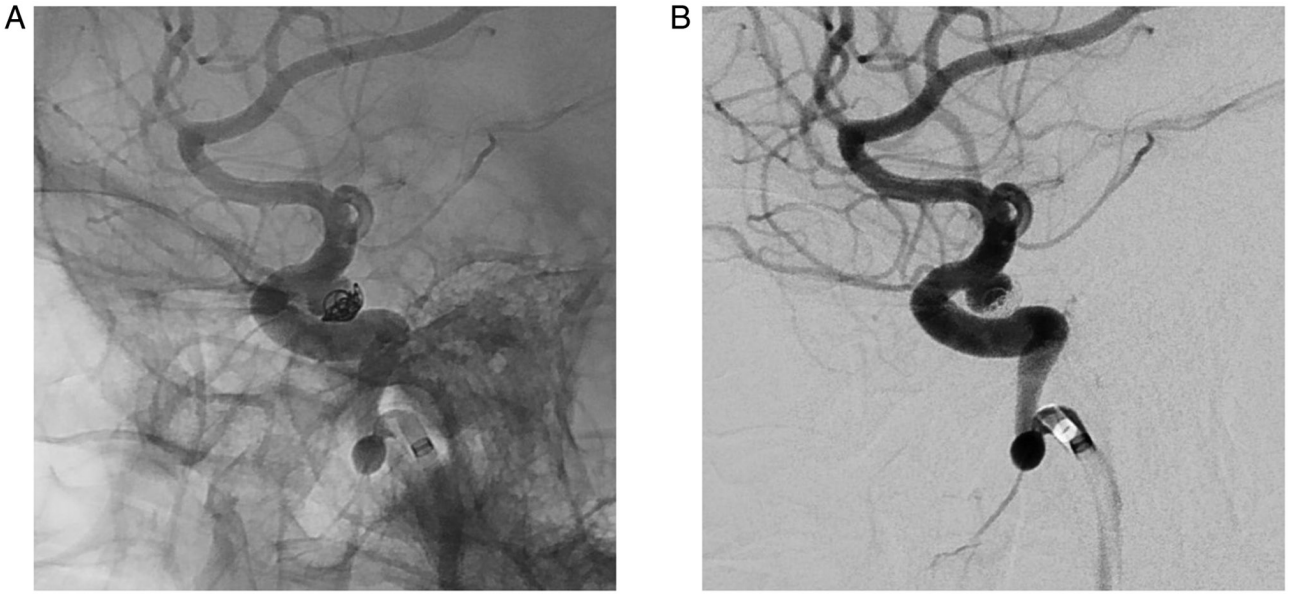

Figure 1. DSA 5 years after first coil embolization. (A) Native and (B) DSA images show a recurred intracranial aneurysm in the left superior hypophyseal artery. The coil mesh is displaced to the dome of the aneurysm. DSA, Digital subtraction angiography.

After positioning a 6F-guiding catheter (Envoy® DA, Codman Neuro, Raynham, MA, USA), two 0.42-mm microcatheters (Excelsior® SL-10®, Stryker Neurovascular) were navigated to the aneurysm sac (for aneurysm selection) and the proximal left middle cerebral artery (for stent delivery) (Fig. 2A and B). Several loops of detachable coils (HyperSoft™ 3D, MicroVention Inc.) were inserted into the aneurysm sac, and stent-assisted neck protection with catheter jailing technique was performed using the Neuroform Atlas® stent (4 mm in diameter and 21 mm in length).

We estimated the length of the stent, and the stent length was calculated using the Syngo Dyna3D system (Siemens Healthineers AG). The planned landing site of stent deployment was from the distal part of the posterior communicating artery to the distal cavernous segment of the left ICA (Fig. 3A). The distal end of the stent was flared in the expected site, and approximately one-third of the stent was partially deployed as usual. Suddenly, the stent-delivery microcatheter partially withdrew to the proximal part of the parent artery. The distal end of the stent was positioned distal to the aneurysm neck, but the proximal end of the stent was still undeployed in the microcatheter. Because of its open-cell strut, we could not resheath the stent and carefully deployed the rest of the stent. The proximal end of the stent was placed on the lacerum segment of the ICA (Fig. 2C and D), and the estimated length from the proximal to the distal marker of the stent was 40 mm-twice the normal length (21 mm) (Fig. 3B and C). We considered the possibilities of a stent fracture or stretching of the stent. To stabilize the damaged stent and remodel the aneurysm neck, we inserted an additional stent (Neuroform Atlas® stent, 4x21 mm) into the distal part of the deployed stent with telescoping manner. Successful coil embolization was achieved with a small neck remnant. During the procedure, the proximal end of the stent was gradually moved distally. Finally, it was in the proximal cavernous segment of the ICA with a length of 30 mm (Fig. 2E, F and 3D).

The patient recovered from the intervention without any neurological deficit. We continued the dual antiplatelet regimen and performed fluoroscopy and MRA 1 year postoperatively. The fluoroscopy showed no change in length from the proximal to the distal marker of the stent (Fig. 4). The stretched Neuroform Atlas® stent was confirmed on magnetic resonance time of flight (MR-TOF) imaging (Fig. 5). The MR-TOF images showed stent struts with poor wall apposition in the cavernous ICA. Additionally, we noticed a gap between the vessel wall and the stent strut due to ovalization of the stent. The stent struts were observed as longitudinally elongated shapes without definite disconnection. The patient has no neurological symptoms and complications until the last follow-up date.

Discussion

This is the first report of stretched and partially fractured Neuroform Atlas® stent. The authors suggested that this rare procedure-related complication was a result of several factors of unique stent designs, unexpected withdrawal of the microcatheter, coiling technique, and vascular anatomy.

As the stent-assisted technique is commonly used for coil embolization for IAs, various laser-cut stents have been developed in the past two decades. The laser-cut stents are divided into closed-cell stents and open-cell stents. The advantages of the closed-cell stent are the ability to resheath the partially deployed stent and less frequent coil prolapse into the stent. The major disadvantage of the closed-cell stent is poor wall apposition. It causes the gap between the stent and vessel wall such as ovalization on greater curvature and hugging on lesser curvature of a sharply curved vessel. In contrast, the open-cell stent has the great advantage of good apposition to the vessel wall on the curved vasculature. The open-cell stent also has good conformability with less straightening of the angle between the parent artery

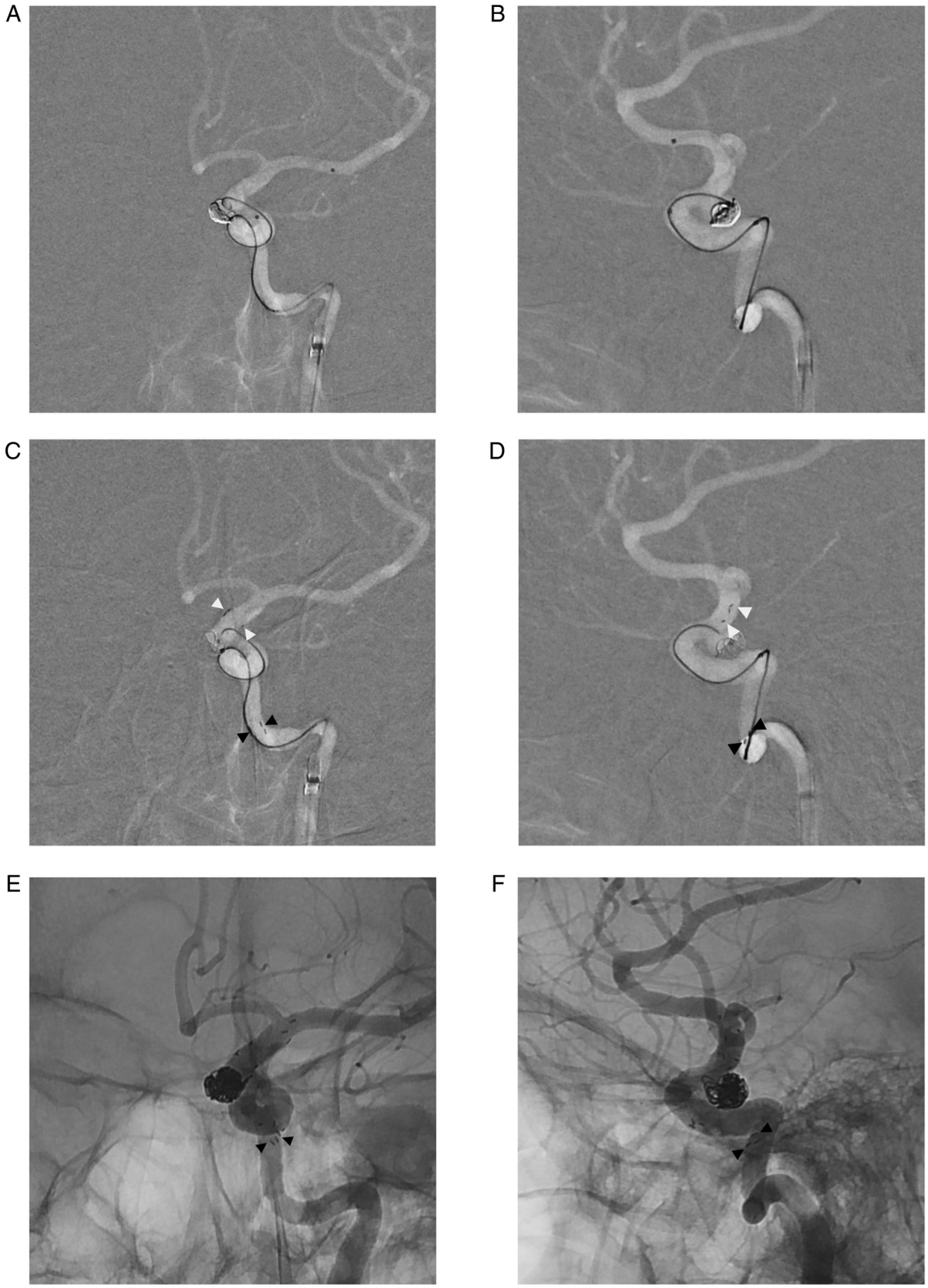

Figure 2. Stent-assisted coil embolization of the recurred left superior hypophyseal artery aneurysm. (A) Two microcatheters were navigated to the aneurysm sac (aneurysm-selecting microcatheter) and (B) the proximal left middle cerebral artery (stent-delivery microcatheter). Several loops of detachable coils were inserted in the aneurysm sac. (C) An unexpected withdrawal of the stent-delivery microcatheter occurred during deployment of the Neuroform Atlas® stent (4x21 mm). (D) The distal end of the stent was positioned in the distal part of the aneurysm neck (white arrowhead), and the proximal end of the stent was in the lacerum segment of the ICA (black arrowhead). The estimated length from the proximal to distal marker of the stent was 40 mm, which is twice the normal length (21 mm). (E) A telescoping stent was inserted into the distal part of the deployed stent. Successful coil embolization was achieved with a small neck remnant. (F) During the procedure, the proximal end of the stent was gradually moved distally. Finally, it was located in the proximal cavernous segment (black arrow) of the ICA, and its length was 30 mm. ICA, internal carotid artery.

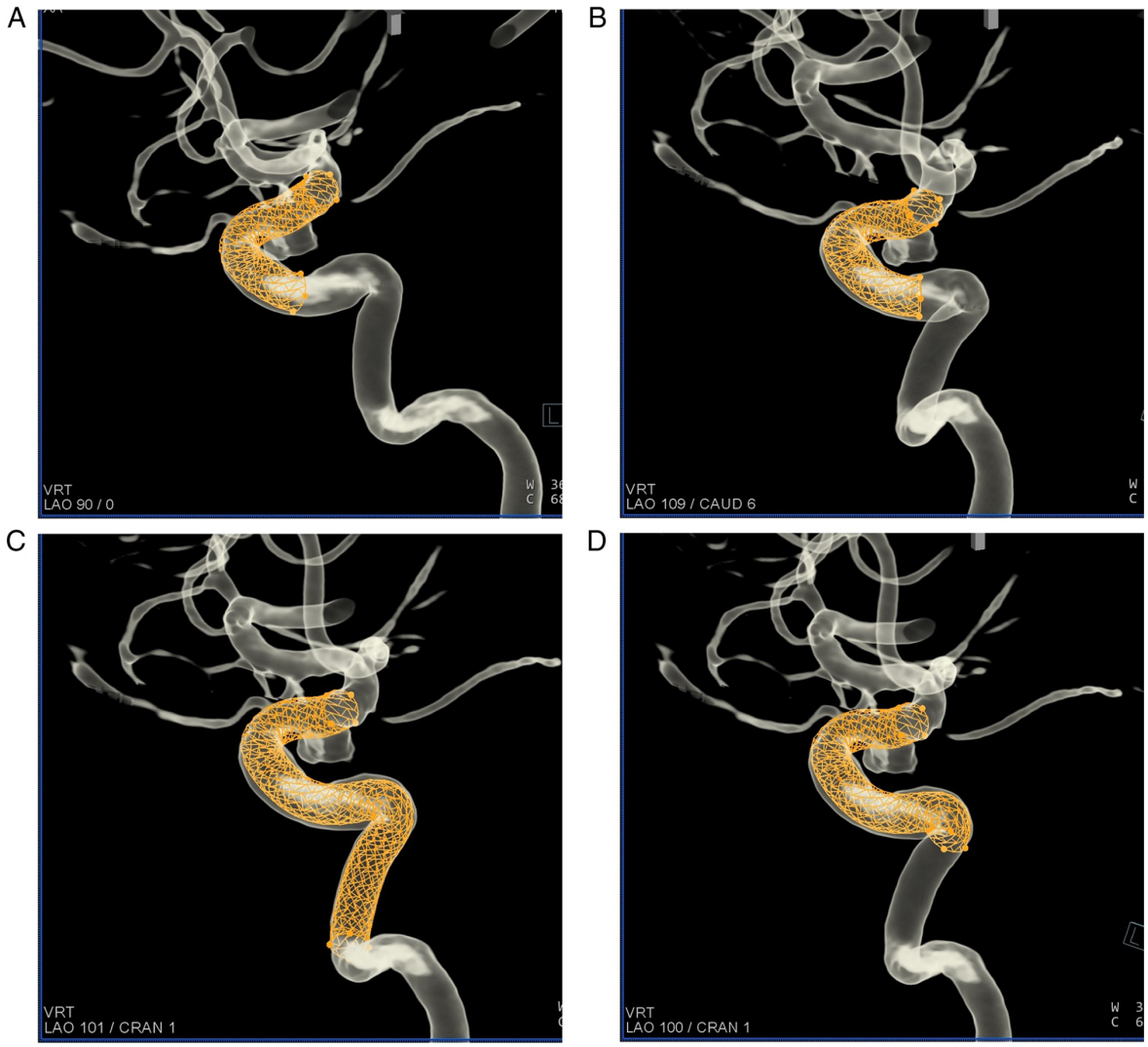

Figure 3. Estimated lengths of the stent. (A) The planned landing site of the Neuroform Atlas® stent (4x21 mm) was from the distal part of the posterior communicating artery to the distal cavernous segment of the left ICA. (B) The image shows the location of the unexpectedly positioned stent. If the stent were not stretched, it would have been located from the distal part of the aneurysm neck to the cavernous segment of the ICA. (C) The stretched stent was ~40 mm in length from the distal part of the aneurysm neck to the lacerum segment of the ICA. (D) The final length of the stent after coil embolization was approximately 30 mm. The proximal marker of the stent as in the proximal cavernous ICA. ICA, internal carotid artery.

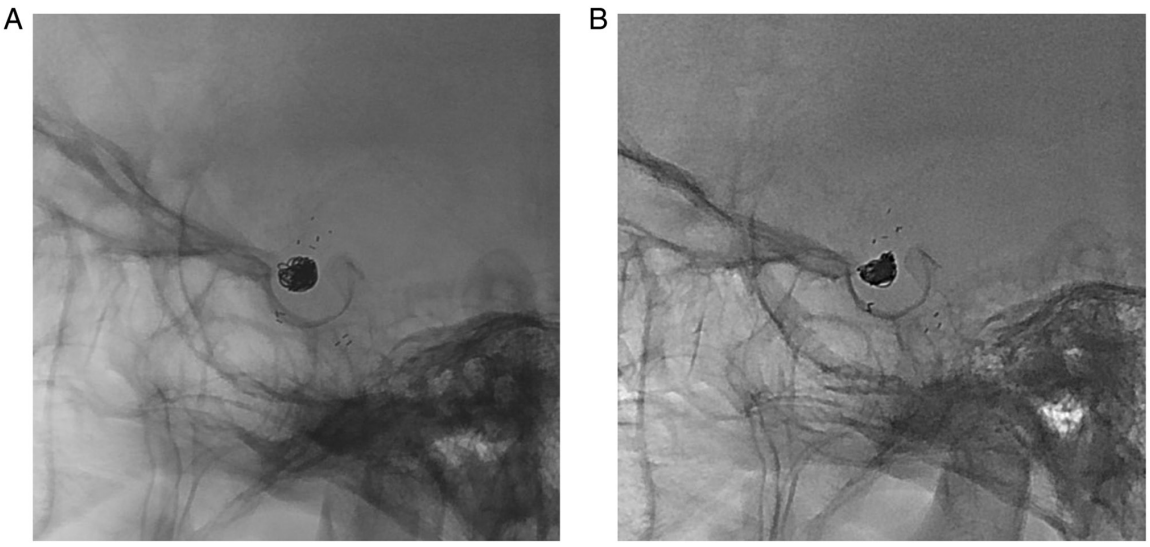

Figure 4. Fluoroscopy images of the coil mesh and stent (A) immediately after surgery and (B) 12 months after surgery. The coil mesh and the stent markers show no change in both images.

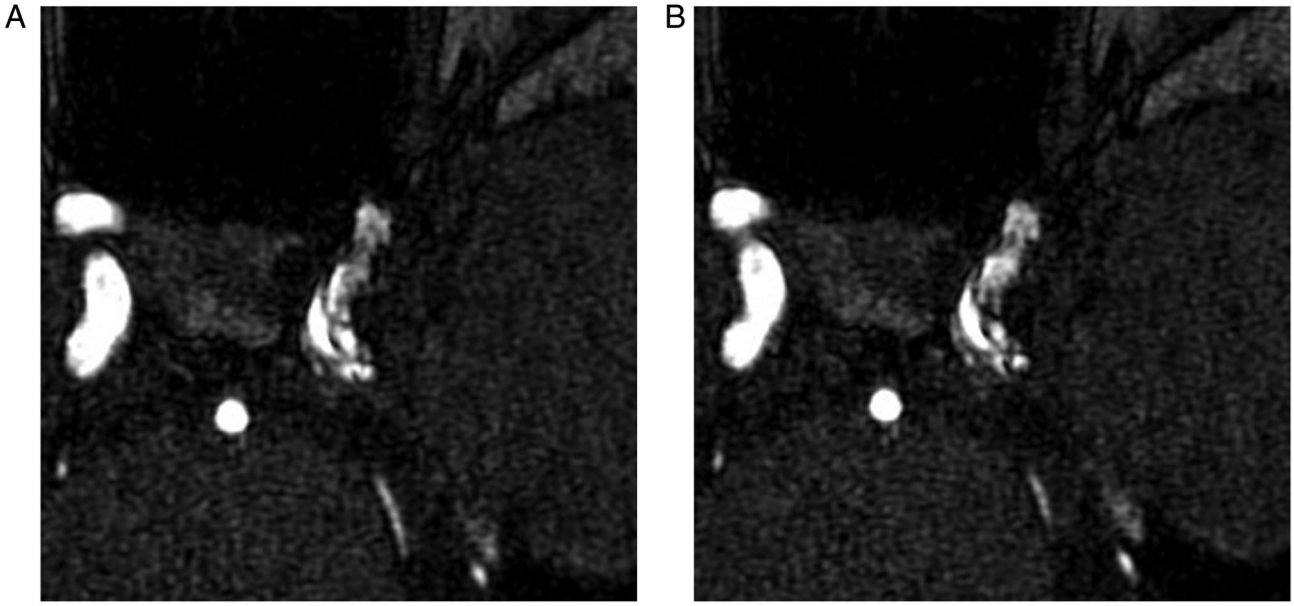

Figure 5. Magnetic resonance time of flight images after 12 postoperative months. (A) The Neuroform Atlas® stent is stretched and appears as longitudinally elongated shapes. (B) The images show the gaps between the vessel wall and stent strut due to the ovalization of the stent without disconnection of the struts.

and the branching artery compared to the closed-cell stent. The disadvantages of the open-cell stent are the kinking phenomenon of the strut into the vessel lumen along the lesser curvature, the gator backing phenomenon of struts herniating onto the aneurysm neck, and the inability to resheath the partially deployed stent (10,11).

The Neuroform Atlas® stent is one of the newest stents that strengthen the advantages of the open-cell stent. It is a self-expandable, low-profile open-cell stent with a hybrid design delivered with a 0.42-mm or 0.43-mm microcatheter. Its low-profile character with thinner struts, fewer strut connections, and increased flexibility improve the stent's trackability and navigation to target vessels (4). Its smaller cell size compared with earlier generations enhances the scaffolding effect with regard to the coil mesh (8). Its unique design with 8 or 12 struts reinforces wall apposition and conformability of the stent (8). Although there were several improvements compared with the earlier generation, its open-cell nature still has disadvantages-the kinking phenomenon, the gator backing phenomenon, and the inability to resheath.

The reported literature confirms the efficacy and safety of the Neuroform Atlas® stent for coil embolization of IA. The procedure-related major adverse events and thromboembolic complications were acceptable, and most of the literature showed very high rates of technical success (Table I) (2-23). However, a few cases were reported with suboptimal deployment in unexpected locations and stent migration during the procedure (2,5-14). The suboptimal stent deployment occurred because of the microcatheter's sudden uncontrolled movement to the proximal part of the target artery during the opening and deployment of the stent. Due to its open-cell design, a partially deployed stent should be fully deployed even when it is positioned at a suboptimal location.

Unexpected catheter movement to the proximal parent artery occurred in this case, as in previously reported articles. The distal end of the stent was maintained in the position of the location of opening; however, the proximal end of the stent, still in the stent-delivery microcatheter, was partially withdrawn to the proximal part. During deployment of the stent using the jailing technique with the aneurysm-selecting microcatheter, the stent strut may have been hooked by the microcatheter already inserted in the IA. Under the firmly positioned aneurysm-selecting microcatheter, the partially deployed stent slipped, and the stent and the microcatheter could have become caught on each other like a hook (Fig. 6A). From the hooked point of the proximal part of the stent, the stent-delivery microcatheter was possibly partially withdrawn, and the stent could have been stretched. The stretched stent resulted in gaps between the stent and the vessel wall at the steep curvature of the ICA. In addition to the above hypothesis, the gator backing phenomenon of the stent strut into the IA could have exacerbated the hooking effect on the stent (Fig. 6B).

To confirm our hypothesis, we performed a simple experiment using three Neuroform Atlas® stents (4x21 mm). We fixed one strut on the distal part of the stent and pulled the proximal end of the stent using two pairs of microforceps (Fig. 7A). All the stents increased in length. The stents were stretched and partially fractured and were about 30 mm in length with two or three disconnections of the struts (Fig. 7B).

Fracture and deformation of intracranial stents have rarely been reported. In contrast, fracture and deformation of stents in extracranial carotid and vertebral arteries, coronary arteries, and peripheral arteries have been established (24-26). The stent fracture results from multiple complex factors involving stent mechanics, vessel anatomy, and physiological factors. Closed-cell stents are more prone to fracture because of their increased rigidity. Additionally, small stent size, overlapping stents, nitinol use, and the use of drug-eluting stents are considered risk factors for stent

Table I. Summary of complications and technical success in previous reports.

Authors	Year	Number of Aneurysm, n (ruptured)	Use of multiple stents, n (%)	Major complications, n (%)	Thrombosis, n (%)	Technical success, %	Suboptimal deployment or migration of stent during procedure, n	(Ref.)
Cay *et al*	2018	55 (0)	-	-	-	100	-	(16)
Ulfert *et al*	2018	37 (2)	0 (0)	Any stroke: 1 (2.7)	-	100	-	(22)
Goertz *et al*	2019	37 (14)	8 (21.6)	Ischemic stroke: 1 (2.7)	1 (2.7)	100	N/A	(17)
Ten Brinck *et al*	2019	27 (10)	10 (37.0)	Any stroke: 4 (14.8)	4 (14.8)	100	Suboptimal deployment: 1	(14)
Tsai *et al*	2019	58 (2)	18 (29.1)	Procedural rupture: 1 (1.7)	3 (5.2)	100	-	(21)
Quintana *et al*	2019	30 (0)	4 (13.3)	Any stroke: 2 (6.7)	1 (3.3)	96.7	Migration: 1	(12)
Ciccio *et al*	2019	55 (3)	55 (100)	Any stroke: 7 (12.5)	8 (14.5)	100	Migration: 2	(9)
Zadiat *et al*	2020	182 (0)	29 (15.9)	Major ipsilateral stroke: 8 (4.4) Neurological death: 1 (0.5)		100	-	(3)
Caragliano *et al*	2020	113 (24)	25 (22.1)	Intra-procedural Cx: 7 (6.2)	4 (3.5)	100	Migration: 3	(8)
Russo *et al*	2020	61 (61)	N/A	Procedural morbidity: 2 (3.2)	22 (36.1)	100	-	(20)
Sweid *et al*	2020	69 (25)	11 (16.0)	Asymptomatic major Cx: 7 (10.1)	6 (8.7)	98.6	Suboptimal deployment: 1	(13)
Burkhardt *et al*	2020	128 (17)	110 (7.8)	Procedural morbidity: 4 (3.1)	6 (4.7)	97.7	Migration: 1	(7)
Aydin *et al*	2020	30 (3)	30 (100)	Any Stroke: 2 (6.7)	-	100	-	(15)
Kim *et al*	2020	33 (11)	0 (0)	-	1 (3.3)	100	Suboptimal deployment: 1	(10)
Baek *et al*	2020	55 (0)	0 (0)	Any Stroke: 1 (1.8)	1 (1.8)	98.2	Suboptimal deployment: 1	(6)
Kwon and Chung	2021	130 (0)	3 (2.3)	Any stroke: 6 (4.6)	5 (3.8)	99.2	Suboptimal positioning: 1	(11)
Arslan *et al*	2021	119 (8)	14 (11.8)	Any stroke: 3 (2.5)	2 (1.7)	99.2	Suboptimal position: 1	(5)
Jankowitz *et al*	2021	116 (0)	40 (34.5)	Major ipsilateral stroke: 4 (3.4) Neurological death: 1 (0.9)	-	100	-	(4)

Table I. Continued.

Authors	Year	Number of Aneurysm, n (ruptured)	Use of multiple stents, n (%)	Major complications, n (%)	Thrombosis, n (%)	Technical success, %	Suboptimal deployment or migration of stent during procedure, n	(Ref.)
Kim and Chung	2021	15 (0)	15 (100)	-	1 (6.6)	100	-	(23)
Monteiro *et al*	2021	64 (0)	N/A	Procedural rupture: 2 (3.1)	-	100	-	(19)
Lefevre *et al*	2021	105 (0)	21 (20)	Any stroke: 5 (4.9)	2 (1.9)	94.7	Suboptimal position: 7	(2)
Kato *et al*	2021	156 (4)	N/A	Any stroke: 3 (2)	2 (1.3)	N/A	N/A	(18)

Cx, complications.

fracture (26,27). Anatomical factors such as vessel calcification, tortuosity, and excessive angulation are well-known risk factors (26,28). Several clinical and laboratory studies have shown that repeated motion of vessels, such as cardiac motion, neck flexion and extension, and joint movement play an important role in stent fracture (29). However, the stent fractures occurred during the follow-up period, and the risk factors of stent fractures were not considered during the procedure.

Most of the deformation of the stent had been observed during our procedure. The Neuroform Atlas® stent has been developed to increase deliverability and wall apposition with the use of thinner struts and fewer strut connections. But this low-profile nature could predispose stents to longitudinal stent deformation (LSD), defined as either shortening or elongation along the longitudinal axis. LSD is known to be more common in cases with balloon expansion of the stent, tortuous and complex vascular anatomy, calcification of the vessel wall, the use of additional devices for the interventional procedure, and devices with fewer strut connections (26,30). Williams et al reported that the proposed mechanisms of LSD are strongly related to compression of the guide catheter and/or microcatheter, passing or withdrawal of a secondary device into or through the stent, and post-dilation of the balloon (31).

This case revealed that unexpected microcatheter withdrawal when using the catheter jailing technique could result in the stretching and fracture of the Neuroform Atlas® stent. Although the Neuroform Atlas® stent has a unique design of low-profile open-cell struts, the quality problem or structural characteristic of the stent was not the cause of this complication. Instead, it may result from the combination of several factors; the steep curvature of the vessel; low-profile open-cell struts of the stent; unexpected microcatheter withdrawal during stent deployment; and hooking of the aneurysm selecting microcatheter with stent strut. Among these factors, unexpected microcatheter withdrawal was the most important, resulting in this complication that could have been avoided. Because unexpected microcatheter withdrawal occurs more frequently in tortuous vessels, physicians should be aware of this possibility when treating patients with complex vascular architecture using the catheter jailing technique. To avoid unexpected microcatheter movement and incorrect stent deployment, the stent should be deployed with appropriate tension of the push wire, careful unsheathing of the microcatheter, and verified firm landing of the distal stent end (10,11). To prevent the thromboembolic event, we maintain the dual antiplatelet regimen with aspirin (100 mg/day) and clopidogrel (75 mg/day) during the follow-up period. Because we have no reliable evidence for the optimal duration of dual antiplatelet therapy in this circumstance, we are planning to continue dual antiplatelet regimen as long as the drug-induced complications do not occur.

In conclusion, stretching and partial fracture of the Neuroform Atlas® stent is a rare complication that may occur in coil embolization for IA with stent-assisted and catheter jailing techniques. We presumed it might result from the combination of several factors; curved vessel; open-cell stent; unexpected microcatheter withdrawal

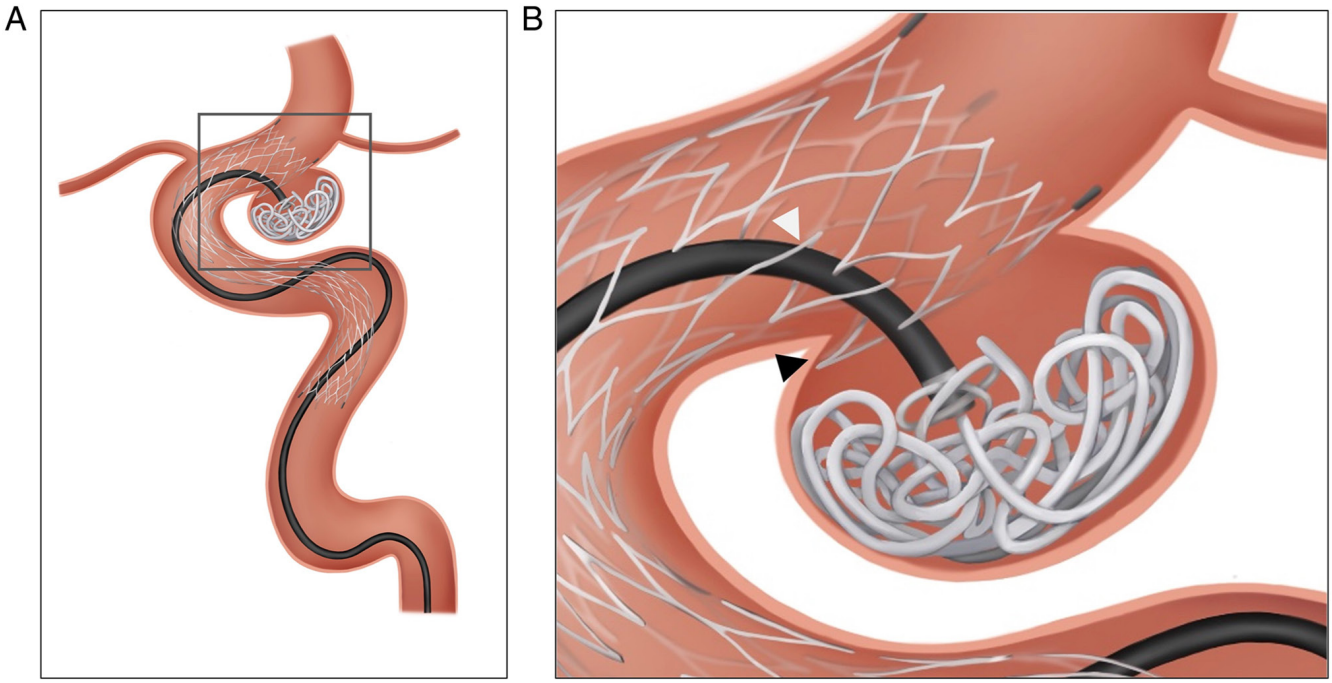

Figure 6. Schematic illustration of the stretched Neuroform Atlas® stent. (A) Unexpected withdrawal of the stent-delivery microcatheter occurred after the opening of the distal end of the stent. The proximal end of the stent, still in the stent-delivery microcatheter, was partially withdrawn to the proximal part of the parent artery. (B) One stent strut may have become hooked onto the aneurysm-selecting microcatheter already inserted in the aneurysm while deploying the stent. Under the firmly positioned aneurysm-selecting microcatheter, the partially deployed stent slipped, and the stent and the aneurysm-selecting microcatheter could have become caught on each other like a hook (white arrowhead). From the proximal part of the stent from the hooked point, the stent-delivery microcatheter was possibly partially withdrawn, and the stent could have been stretched. The stretched stent resulted in gaps between the stent and the vessel wall on the steep curvature of the internal carotid artery. Additionally, the gator backing phenomenon of the stent strut into the intracranial aneurysm could have exacerbated the hooked effect of the stent (black arrowhead).

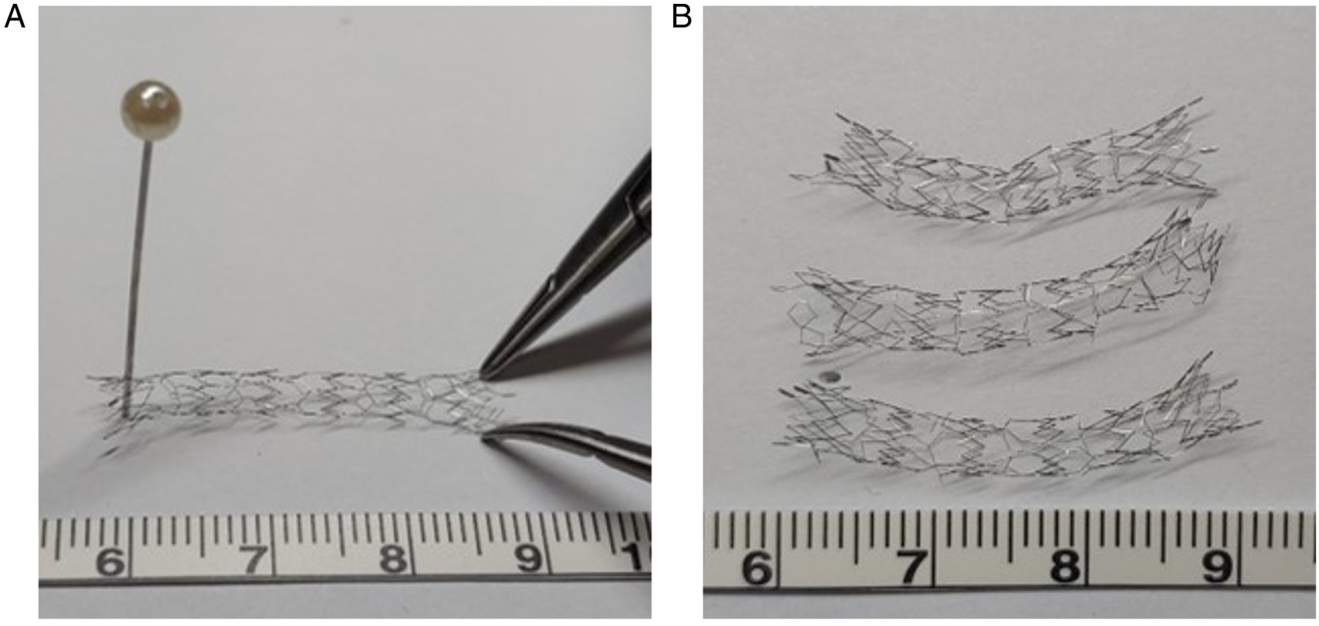

Figure 7. A simple experiment using three Neuroform Atlas® stents of 4-mm in diameter and 21-mm in length. (A) One strut was fixed on the distal part of the stent and the proximal end of the stent was pulled using two pairs of microforceps. (B) All the stents increased in length. The stents were stretched and partially fractured and were ~30 mm in length with two or three disconnections of the struts.

during stent deployment; and hooking of the aneurysm selecting microcatheter with stent strut. Physicians should note the possibility of this complication when unexpected microcatheter withdrawal occurs during stent deployment when using the catheter jailing technique. Understanding the stent design and careful manipulation in stent deployment could prevent this complication, which can be challenging to resolve.

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Authors' contributions

HS introduced and designed the concept of this study. HK and HS confirm the authenticity of all the raw data. HK and HS obtained and analyzed the patient's information and wrote the manuscript. HS reviewed the discussion part of the clinical manifestations, imaging features and brief experiment. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

The IRB committee of Kyung Hee University Hospital at Gangdong exempted this case study from the IRB review approval as following the enforcement rules (article 13 and 33 of the Bioethics and Biosafety Act) and article 7 of the KHNMC SOP.

Patient consent for publication

Written informed consent for publication of the clinical details and clinical images was obtained from the individual participant.

Competing interests

The authors declare that they have no competing interests.

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