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TECHNICAL NOTE

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Modified pressure-cooker technique (PCT) using extra-soft Kaneka coils improves embolization of high-grade cerebral arteriovenous malformations: a technical note

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Abstract

Endovascular embolization techniques are showing an extraordinary potential to treat patients suffering from complex neurovascular malformations. The embolization with liquid embolic agents via Onyx is a prominent approach to treat arteriovenous malformation (AVM). However, intraoperative reflux of the liquid agents can be very challenging and, thus, is impairing full success of endovascular treatment. A possible technique to prevent intraoperative endovascular reflux is the pressure-cooker technique (PCT) utilizing coils to build a wedge proximal to the AVM. Few modifications of the PCT have been developed in the recent years to improve effectiveness of embolization procedure. Hereby, we present a novel PCT modification utilizing extra-soft Kaneka coils and glue to build well-fitting wedges. After the application of extremely soft bare coils with high trackability, flexibility and crossability, liquid agents can be injected with reduced reflux. We think the pressure-cooker technique with extra-soft Kaneka coils enables more efficient embolization in even farther, tinier and more tortuous target vessels. This technical note presents two illustrative patient cases with treatment-refractory, high-grade cerebral arteriovenous malformations which were successfully treated via embolization with PCT in which the plug was formed with Kaneka coils.

Keywords Brain AVM, Coils, Embolization, Glue, Onyx, Kaneka, Pressure cooker, PCT, Endovascular

Introduction/Background

While a variety of approaches to treat arteriovenous malformations (AVMs) have been developed, treatment of cerebral AVMs is still a challenging task. Possible treatment plans can contain endovascular embolization, microsurgical resection and/or stereotactic radiosurgical [16]. However, it still remains difficult for physicians to identify accurately the right indications in each individual case [4]. In particular, minimal-invasive endovascular embolization via Onyx is an efficient and promising approach to treat patients with AVMs and dural arteriovenous fistulae (DAVF). This treatment is frequently used in clinical life for different frameworks and for varying target vessels in patients with AVMs. However, the technique must be adapted for the best outcome and for the prevention of harmful complications.

For instance, reflux in endovascular embolization via liquid agents like Onyx can lead to further complications and, as well, to inefficient embolization of the malformation. One prominent technique to prevent reflux of liquid agents is the pressure-cooker technique. The pressure-cooker technique (PCT) was first described by Chapot et al. as a promising technique to prevent intraoperative reflux during embolization of AVMs by forming a plug in

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the feeding arteries prior to the tip of the embolization catheter with injectable coils and glue [3]. And indeed, several studies reported the benefits of using PCT [1, 7, 8].

Since in large or in high-flow feeders the exact position of the flow coils cannot be controlled after injection we altered the PCT by using coils that can be implanted through a flow-directed microcatheter. The authors of this paper find this variation of the PCT as a beneficial approach to achieve more flexibility while maintaining or even enhancing the efficiency of the procedure.

In this technical note, we describe a reflux-preventing approach via pressure-cooker technique using bare coils and glue based on two clinical cases of AVM patients we have successfully treated.

Clinical presentation

First case

The first patient is a 22-year-old male who became symptomatic for the first time in 2017 through a generalized epileptic seizure. Initially, to clarify the seizure, the patient underwent diagnostic computed tomography (CT), brain magnetic resonance imaging (MRI) and digital subtraction angiography (DSA) in which a high-grade temporal, left-sided AVM ($4.5 \times 3 \times 2$ cm, Spretzler-Martin Grade III [15], was diagnosed (Figs. 1, 2). The patient

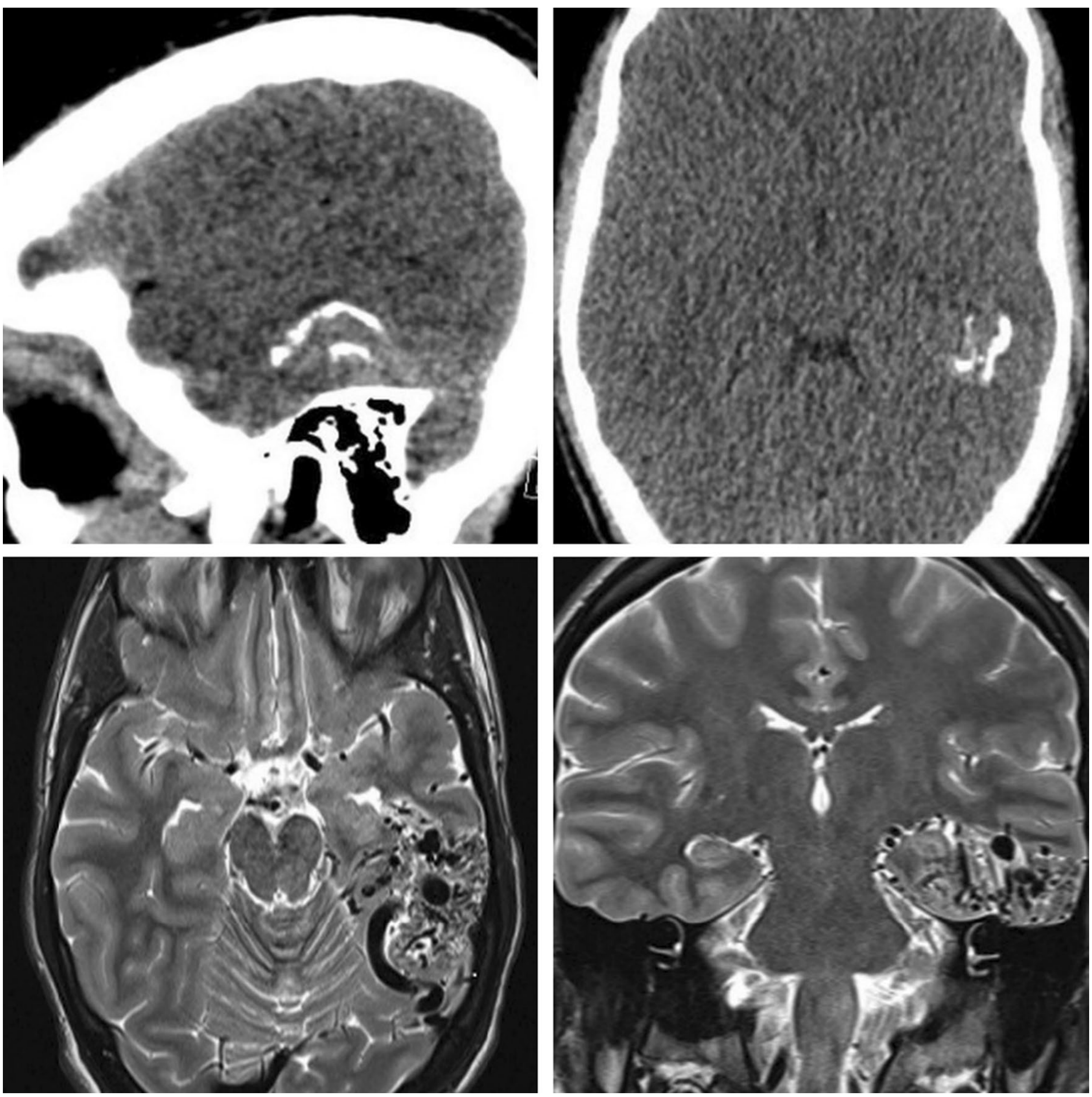

Fig. 1 Images showing the temporal, left-sided AVM in initial soft-tissue CT in sagittal (upper level, left) and in axial (upper level, right) and coronal (lower level, left) in T2-MRI with Gadolinium (GD) injection

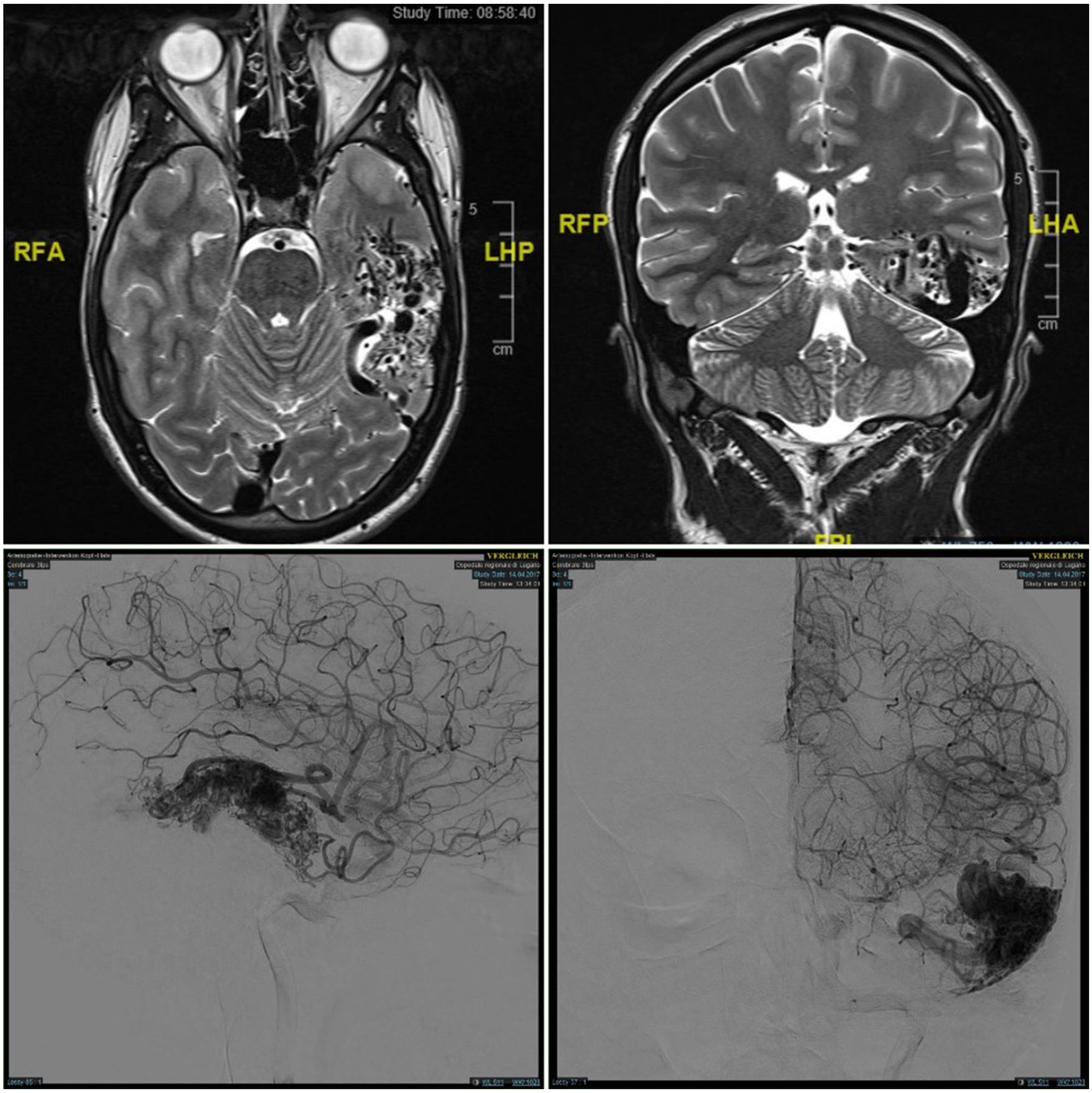

Fig. 2 T2-MRI with GD in axial (upper level, left) and in coronal (upper level, right) and initial DSA in sagittal (lower level, left) and in coronal (lower level, right) showing the temporal AVM from 2017

was free of seizures due to medication (Keppra 1 g 1–0–1) until January 2019. In January 2019, the patient was again hospitalized due to a partially complex seizure. Possible reasons for the seizure were missing compliance for taking anti-epileptic medication, lack of sleep or intake of alcohol (positive provocation test). As part of the interdisciplinary neurovascular conference in July 2019, an embolization therapy was recommended which the patient has agreed on.

Second case

The second patient is a 20-year-old female who became symptomatic due to a first, focal epileptic seizure in the left arm and headaches in 2013. After clinical evaluation and medical imaging, we found a central, high-grade AVM (Spetzler-Martin-Grade 4) in the right hemisphere (Figs. 3, 4). This patient underwent several partial embolization due to the size of the AVM.

Technical description

In both patients, the PCT with wedges consisting of Kaneka coils and glue was performed (Fig. 5). Patients were under general anesthesia with endotracheal intubation, and they received full heparinization (70 IU/kg). Transfemoral access was performed with a 6-French (patient 1) and an 8-French (patient 2) guiding catheters

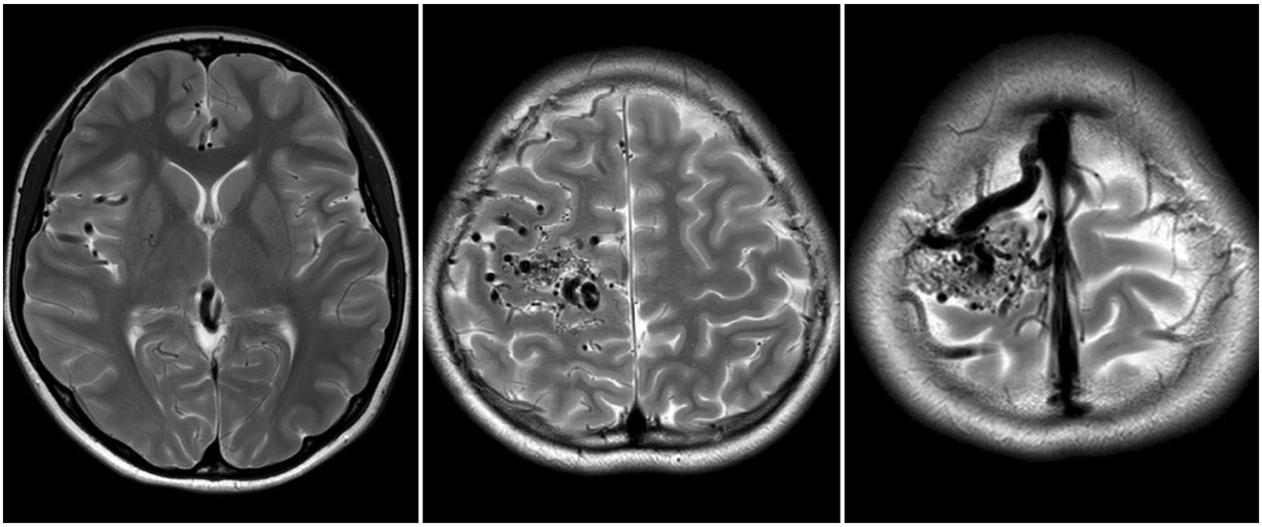

Fig. 3 Pre-operational T2-MRI with gadolinium (GD) injection

via Seldinger technique. Subsequently, we pushed a guiding catheter (Benchmark) through a diagnostic catheter (5-French, 125 cm) with standard wire to probe the left arteria vertebralis. After this, we inserted a further guide catheter (053 Neuron Intracranial access system) through exchange via a standard wire with diagnostic catheter (5-French, 125 cm) to probe the arteria vertebralis on the right side. Then, arteriography-series in posterior-anterior (PA) from lateral and in 3D were captured. Since in large or in high-flow feeders the exact positioning of the flow coils cannot be controlled after injection we altered the PCT by using coils that can be implanted through a flow-directed microcatheter (Fig. 5).

First patient

In the first patient, a micro-wire and a microcatheter (Marathon and Apollo 1.5-French, TIP 1.5 cm) were placed in a dominant feeder as close as possible to the nidus. In the microcatheter injection, a flow to the posteromedial compartment of the nidus was present. Subsequently, a coil-embolization (Kaneka coil 3D, 2.5 mm × 6 mm) and liquid embolization (0.1 ml NBCA 1:1) through a Marathon-microcatheter in proximal position with wedge-building (pressure-cooker technique) were achieved (Fig. 6). Afterward, a further liquid embolization (2.5 ml Onyx 18 and 20) with penetration of the nidus and with closure of the feeders was executed successfully.

Then, we probed further dominant feeders of posterolateral compartment of the nidus via micro-wire and microcatheter (Marathon and Apollo 1.5 French, TIP 1.5 cm). A further liquid embolization injection (1.3 ml Onyx 20 and 18) under flow-arrest with pressure-cooker technique (Kaneka coil 3D, 4 mm × 6 cm and 2 mm × 6 cm) was achieved. In the control-series a complete embolization of the posterior compartment and a major part of the central compartment could be visualized (Fig. 7).

Second patient

In the second patient, several partial embolization without PCT were performed prior to the third and last embolization with PCT via coils (Fig. 8).

In the DSA, the fronto-parietal rest-AVM on the right side showed dominant feeders from the arteria cerebri media and from the arteria cerebri anterior. Thereto, we explored the arteria cerebri media via microcatheter (Marathon-Flow-directed, 162 cm) and micro-wire (Asahi Chikai 10). Patient showed no motoric impairment after provocation test with Lidocaine (20 mg) and Etomidate lipuro (1.0 mg). Then injection of liquid agents (Onyx 18, 1.5 ml) close to the feeders and with moderate penetration of the nidus was performed. After exploration via microcatheter (Apollo 1.5 French, 3 cm) and micro-wire (Asahi Chikai 10), we attempted coil-embolization (Kaneka coil 3D, 3 mm × 3 cm, 3 mm × 6 cm, 4 mm × 6 cm) and liquid embolization (NBCA, 1:1) through microcatheter (Marathon) in proximal position with wedge-building (PCT, Fig. 9). Following liquid embolization (1 ml Onyx20 and 3 ml Onyx18) via microcatheter (Apollo 1.5 French, 3 cm) in distal position with closure of the feeders and with appropriate penetration of the nidus was proceeded. In the DSA, it could be shown that a 30–40% reduction of the AV-shunt flow could be reached (Fig. 10).

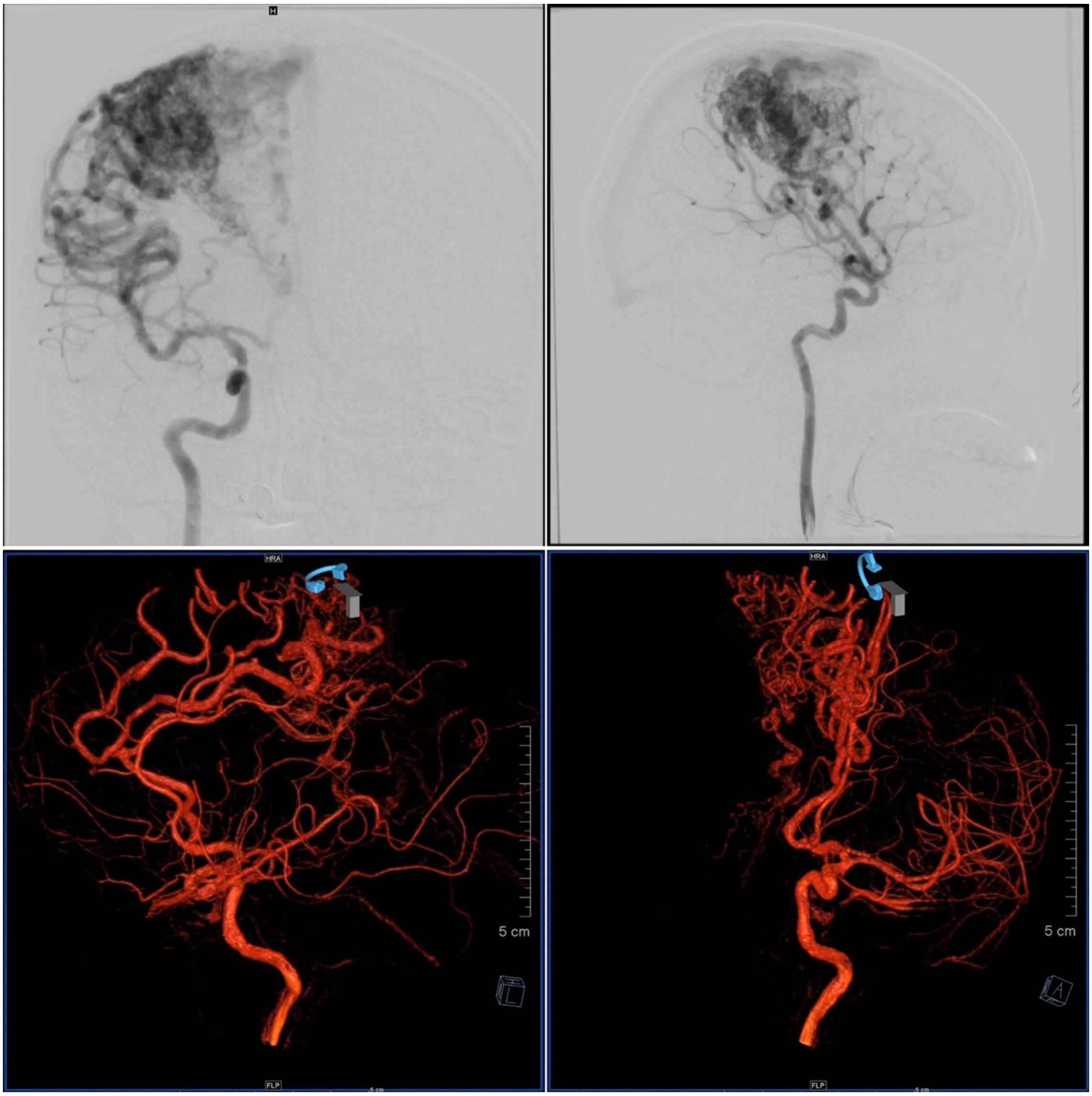

Fig. 4 Digital subtraction angiography (DSA) and volume-rendering technique (VRT) illustration of the high-central, right-sided AVM in right hemisphere

Discussion

Several reports have presented the PCT and different modifications of the technique [3, 7, 8, 10]. The pressure-cooker technique showed to be very reliable for intraoperative prevention of reflux of liquid agents in endovascular embolization. In addition, it could be seen that different modifications are performed more efficiently when indications were chosen carefully and when the setting, which is set by the pathology, is giving the right framework for application of the specific PCT modification. We see certain advantages of this modified version of the transarterial PCT:

- We can reach more into farther and tinier vessels with extra-soft Kaneka coils compared to other wedge-modalities of the PCT
- Due to the extra-soft configuration, we can place the Kaneka coils more proximal to the nidus than before and, thereto, we reach better embolization performance
- Due to the extra-soft configuration, we can build wedges with higher density and, thereto, we reduce the collateral damage of healthy vessels by reflux of liquid agents

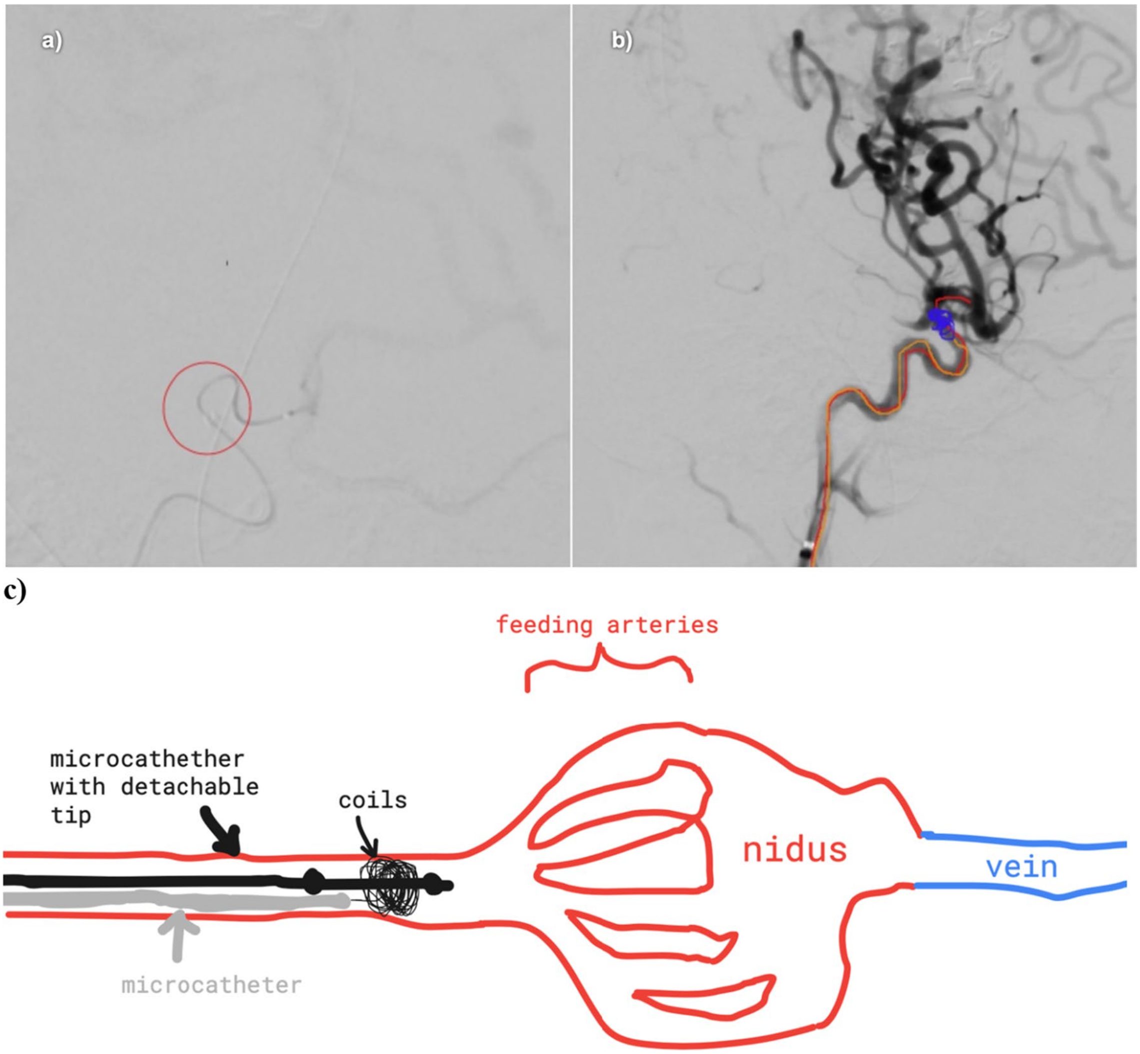

Fig. 5 Visualization of the pressure-cooker technique via intraarterial coiling-wedge. **a** Placement of the Kaneka coil wedge, AP view, **b** Illustration of the microcatheters and coil wedge placements, AP view, **c** Diagrammatic sketch of transarterial PCT

When to consider transarterial PCT with coiling-wedge modification

The PCT is an efficient approach to prevent endovascular reflux of liquid agents in liquid embolization. However, the different modifications of the PCT are more applicable for certain AVMs and DAVFs. The size, location, intravascular flow-attributes and the surrounding structures, which project on patient symptomology, are important factors to determine the appropriate techniques. We have identified these factors as important indicators for PCT with coiling-wedge modification:

- In cases of far and/or tiny feeder-vessel structures
- In cases of large and high-flow feeders in which the exact positioning of the flow coils can be difficult after injection

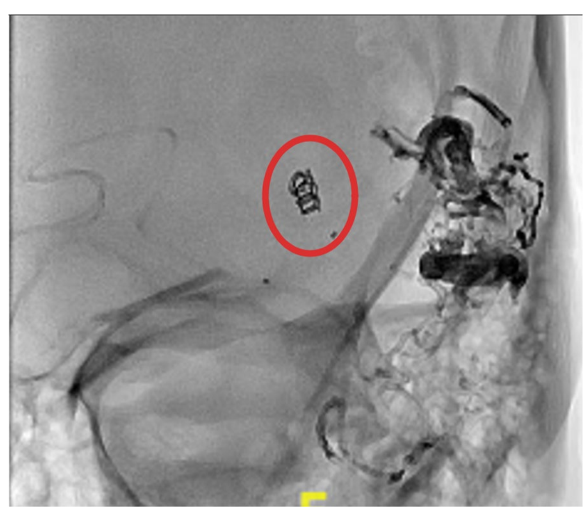

Fig. 6 Angiographic imaging of positioning the coil wedge, AP view

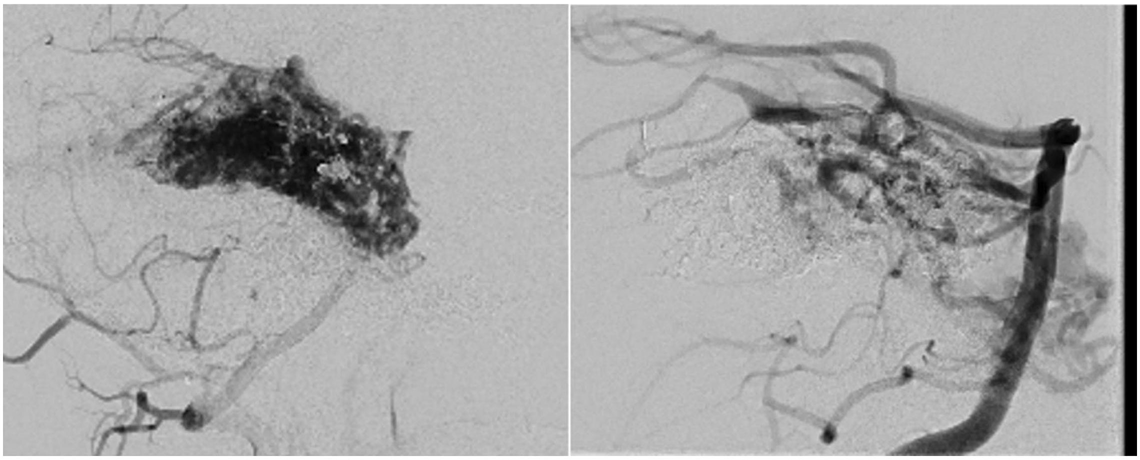

Fig. 7 DSA images before (left) and after (right) of embolization via PCT with Kaneka coil wedge in lateral view

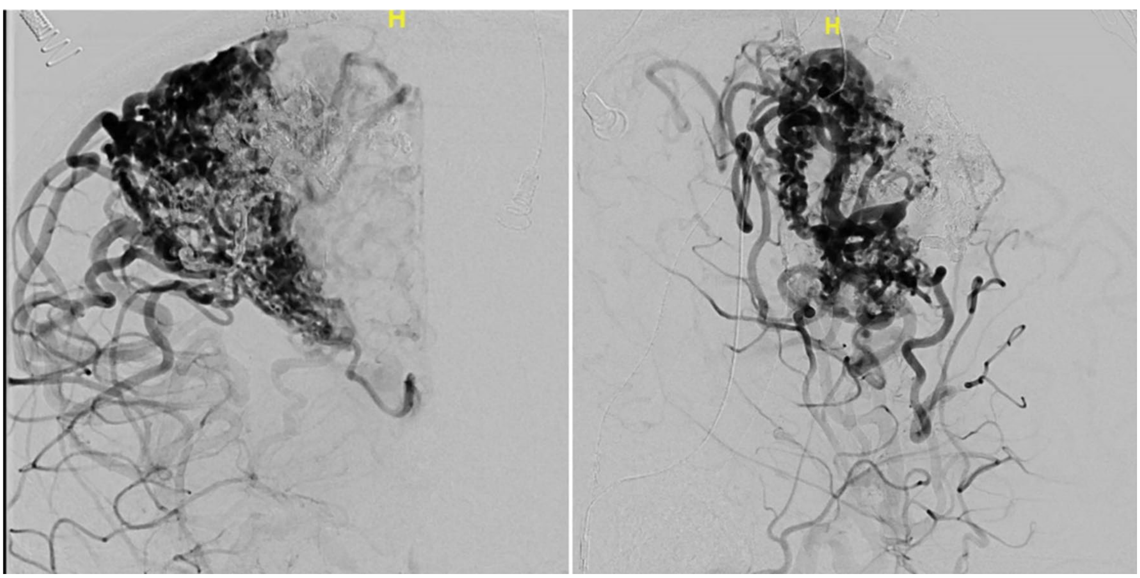

Fig. 8 DSA imaging. After first (left, AP view) and second (right, lateral view) embolization without PCT

- high-grade AVMs (Spetzler-Martin-Grade ≥ 3)
- hemorrhagic AVMs/DAVFs

Is the usage of detachable microcatheter recommended?

As shown in some reports, the usage of a detachable microcatheter can have several advantages and disadvantages [6, 14]. The detachment can require more physical power than expected and, therefore, lead to unexpected damage of the surrounding structures [12]. However, the usage of detachable microcatheter can help to embolize more efficiently and more completely the surrounding and draining vessels [13].

Conclusions

We found that transarterial embolization via modified pressure-cooker technique (PCT) with one or multiple wedges leveraging extra-soft Kaneka coils enabled successful treatment of patients with high-grade AVMs. In our cases, we presented multiple patients with treatment refractory AVMs which could be successfully treated by utilizing a modern and modified PCT to maximize

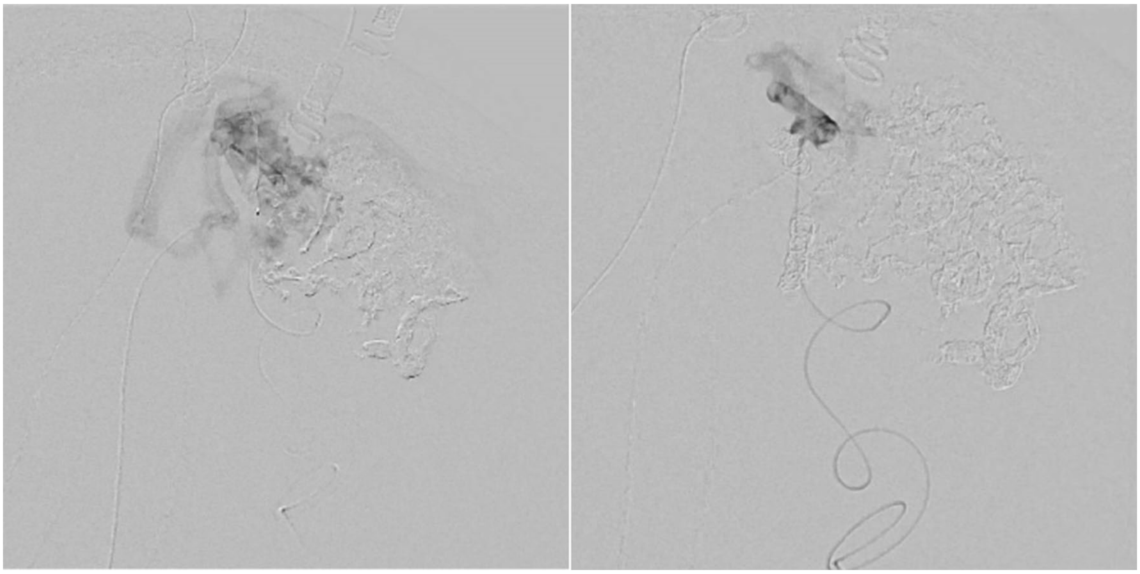

Fig. 9 DSA imaging. Microcatheter injection in MCA branch, **a** before and **b** after building a wedge of coils and glue in lateral view

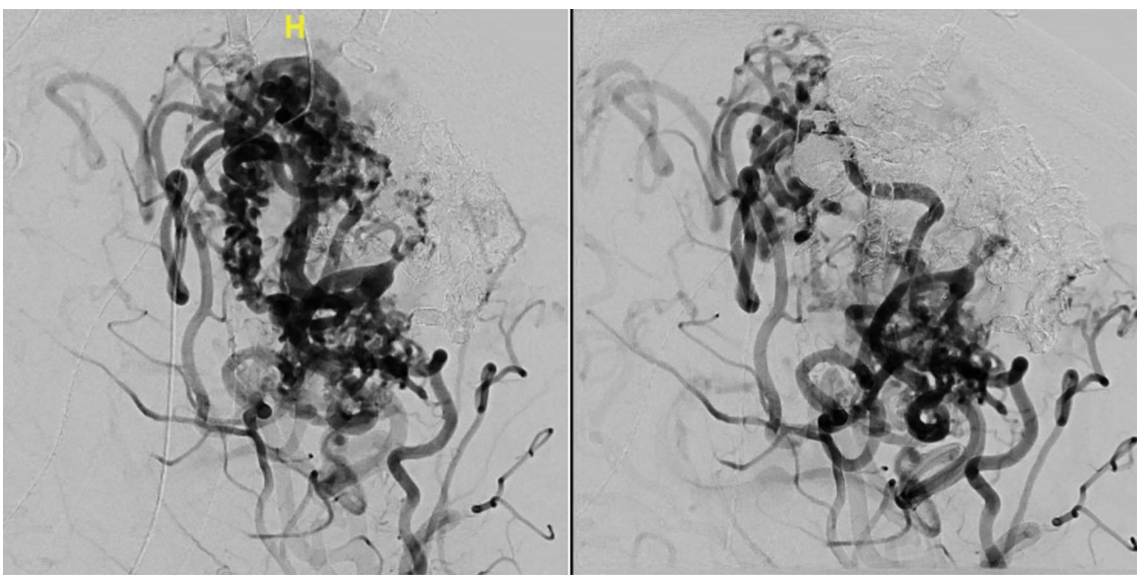

Fig. 10 DSA imaging. Before and after embolization with PCT via Kaneka coils in lateral view

embolization effect. Thus, the authors consider this modification of the PCT to enhance outcome of treatment refractory high-grade AVM patients.

Abbreviations

AV	Arteriovenous
AVM	Arteriovenous malformation
DAVF	Dural arteriovenous fistula
DSA	Digital subtraction angiography
GD	Gadolinium
PCT	Pressure-cooker technique
MRI	Magnetic resonance imaging
NBCA	N-butyl cyanoacrylate
VRT	Volume-rendering technique

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Author contributions
MY was involved in writing—original draft preparation, visualization, formal analysis, review and editing. KB contributed to writing—review and editing, supervision. M-NP was involved in writing—review and editing, resources, supervision. All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate/for publication
Written consents for participation and publication were obtained from all patients before the procedures after clarification of the benefits and risks of the procedures. The study was approved by the medical faculty of the university hospital in Basel, Switzerland.

Competing interests
The authors declare no competing interests.

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References
1. Altschul D, Biswas A, Nakhla J, Echt M, Gordon D. Novel double catheter technique with detachable microcatheter for the treatment of arteriovenous malformations: a technical note. Surg Neurol Int. 2016. https://doi.org/10.4103/2152-7806.196380.
2. Bhogal P, Al-Matter M, Hellstern V, Bäzner H, Ganslandt O, Henkes H, AguilarPérez M. High-grade Dural arteriovenous fistulas: use of Kaneka ED coils with the marathon microcatheter for transvenous coil embolization. Clin Neuroradiol. 2019. https://doi.org/10.1007/s00062-018-0724-y.
3. Chapot R, Stracke P, Velasco A, Nordmeyer H, Heddier M, Stauder M, Schooss P, Mosimann PJ. The pressure cooker technique for the treatment of brain AVMs. J Neuroradiol. 2014. https://doi.org/10.1016/j.neurad.2013.10.001.
4. Conger A, Kulwin C, Lawton MT, Cohen-Gadol AA. Endovascular and microsurgical treatment of cerebral arteriovenous malformations: current recommendations. Surg Neurol Int. 2015. https://doi.org/10.4103/2152-7806.153707.
5. Fessia P, Kummer H, Kuribayashi H, Tommasini D, Van De Velde F. Curing of LHC main dipole coils insulated with all polyimide PIXEO® adhesive tape. IEEE Trans Appl Supercond. 2006. https://doi.org/10.1109/TASC.2006.869975.
6. Flores BC, See AP, Weiner GM, Jankowitz BT, Ducruet AF, Albuquerque FC. Use of the Apollo detachable-tip microcatheter for endovascular embolization of arteriovenous malformations and arteriovenous fistulas. J Neurosurg. 2019. https://doi.org/10.3171/2017.9.JNS17397.
7. He Y, Bai W, Li T, Hui FK, He Y, Xu B. Curative transvenous embolization for ruptured brain arteriovenous malformations: a single-center experience from China. World Neurosurg. 2018. https://doi.org/10.1016/j.wneu.2018.04.223.
8. Houdart E, Labeyrie MA, Lenck S, Saint-Maurice JP. Treatment of AVM: endovascular methods. In: Brain arteriovenous malformations: pathogenesis, epidemiology, diagnosis, treatment and outcome. 2017. https://doi.org/10.1007/978-3-319-63964-2_10.
9. Kojima A, Onozuka S, Ishikawa M, Akiyama T, Kimura H. Usefulness of the ED Coil Inifini for the treatment of direct carotid-cavernous fistula: techinical note. J Neuroendovasc Ther. 2012. https://doi.org/10.5797/jnet.6.61.
10. Koyanagi M, Mosimann PJ, Nordmeyer H, Heddier M, Krause J, Narata A-P, Serwi AE, Stracke CP, Chapot R. The transvenous retrograde pressure cooker technique for the curative embolization of high-grade brain arteriovenous malformations. J Neurointerv Surg. 2020. https://doi.org/10.1136/neurintsurg-2020-016566.
11. Maimon S, Strauss I, Frolov V, Margalit N, Ram Z. Brain arteriovenous malformation treatment using a combination of onyx and a new detachable tip microcatheter, SONIC: short-term results. Am J Neuroradiol. 2010. https://doi.org/10.3174/ajnr.A1959.
12. Mendes GAC, Iosif C, Silveira EP, Waihrich E, Saleme S, Mounayer C. Transvenous embolization in pediatric plexiform arteriovenous malformations. Neurosurgery. 2016. https://doi.org/10.1227/NEU.0000000000001057.
13. Naito I, Iwai T, Negishi M, Sasaki T. Endovascular treatment of direct carotid-cavernous fistulas using detachable coils. Interv Neuroradiol. 2000. https://doi.org/10.1177/15910199000060s118.
14. Paramasivam S, Altschul D, Ortega-Gutiarrez S, Fifi J, Berenstein A. N-butyl cyanoacrylate embolization using a detachable tip microcatheter: initial experience. J Neurointerv Surg. 2015. https://doi.org/10.1136/neurintsurg-2014-011165.
15. Spetzler RF, Martin NA. A proposed grading system for arteriovenous malformations. J Neurosurg. 1986. https://doi.org/10.3171/jns.1986.65.4.0476.
16. Solomon RA, Connolly ES Jr. Arteriovenous malformations of the brain. N Engl J Med. 2017;377(5):498. https://doi.org/10.1056/nejmc1707399.
17. Van Os J, Hanssen M, Bak M, Bijl RV, Vollebergh W. Do urbanicity and familial liability coparticipate in causing psychosis? Am J Psychiatry. 2003. https://doi.org/10.1176/appi.ajp.160.3.477.
18. Zhang G, Zhu S, Wu P, Xu S, Shi H. The transvenous pressure cooker technique: a treatment for brain arteriovenous malformations. Interv Neuroradiol. 2017. https://doi.org/10.1177/1591019916682357.

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