Custom-made donut technique: An innovative approach to treating scalp arteriovenous fistula

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ABSTRACT

Scalp arteriovenous fistulas are rare, high-flow vascular anomalies, often of post-traumatic origin. Their management remains a subject of debate owing to the limited number of reported cases. This study presents a novel approach for the treatment of a post-traumatic right mastoid scalp arteriovenous fistula in a patient with a history of multiple unsuccessful treatments. A customized, in-house three-dimensional-printed device, designed in a donut shape, was used to enhance the precision of direct puncture embolization. This approach aimed to confine embolization exclusively to the fistula site, minimizing the risk of inadvertent occlusion of adjacent vessels and subsequent cutaneous necrosis. The treatment strategy combined endovascular embolization using precipitating hydrophobic injectable liquid with surgical resection in a single-stage procedure. The intervention was completed without intraoperative or postoperative complications. Follow-up assessments confirmed complete fistula occlusion with no recurrence and satisfactory functional and aesthetic outcomes. This innovative technique highlights the potential advantages of patient-specific three-dimensional-printed devices in optimizing embolization strategies for complex vascular malformations. (J Vasc Surg Cases Innov Tech 2026;12:102092.)

Keywords: Arteriovenous fistula; Embolization; Combined treatment; Scalp; Surgical approach

Arteriovenous fistulas (AVFs) are abnormal direct connections between arteries and veins without a capillary bed. They are usually post-traumatic, unlike congenital arteriovenous malformations. Other scalp AVF (S-AVF) causes include hair transplantation and iatrogenic or idiopathic origins.

Two main pathogenetic theories exist. In type 1, vessel trauma causes a vasa vasorum rupture leading to a pseudoaneurysm that drains into a vein, forming a fistula. In the laceration theory, simultaneous arterial and venous injury creates a direct communication.[1]

In the literature, the most widely used classification remains that of Yokouchi et al,[2] which divides the fistulas into three types: type A features a single fistula fed by a single proximal artery; type B involves a single fistula supplied by multiple arteries; and type C is characterized by multiple fistulas, with a plexiform arterial supply and prominently dilated draining veins.

An additional entity to these three types is a cirsoid aneurysm, a rare type of fistula with only 200 cases reported in the literature, characterized by a serpentine appearance.[3]

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This article reports a rare case of a cirsoid aneurysm-type S-AVF in the left temporo-occipital region, treated with a single-session combined endovascular and surgical approach. A custom three-dimensional (3D)-printed donut-shaped device uniquely enabled selective embolization of the fistulous point while preserving surrounding vessels.

CASE REPORT

A 56-year-old man presented with a 3-cm nodular, tense-elastic, pulsatile swelling in the left temporo-occipital region, present since childhood after trauma (Fig 1). He reported discomfort from continuous pulsations but no pain or bleeding. Two prior surgical excisions had failed. Magnetic resonance imaging, computed tomography (CT) angiography, and arteriography confirmed a cirsoid AVF without intracranial involvement. After multidisciplinary evaluation, a combined direct puncture embolization and surgical excision in a single session was planned. A custom CAD-CAM donut-shaped device was used to contain embolic material. The patient provided informed consent for treatment and publication in accordance with the Declaration of Helsinki.

CT segmentation and CAD. The donut creation started with the importation of the DICOM data from the CT scan into the *Mimics inPrint* Software (Materialise); the segmentation process allowed isolation of a detailed 3D reconstruction of the skull and enabled precise visualization of the AVF in relation to the bony surface. This strategy allowed for accurate assessment of the nidus size, shape, and spatial orientation.

Subsequently, the 3D model was exported in STL format into *Blender* software (Blender Foundation) where a custom-made, donut-shaped device was designed (Fig 2). The donut's inferior surface was modeled to conform to the curvature of the patient's skull, derived directly from the segmented CT data. Its overall size was intentionally limited to encompass only the

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Fig 1. Preoperative appearance.

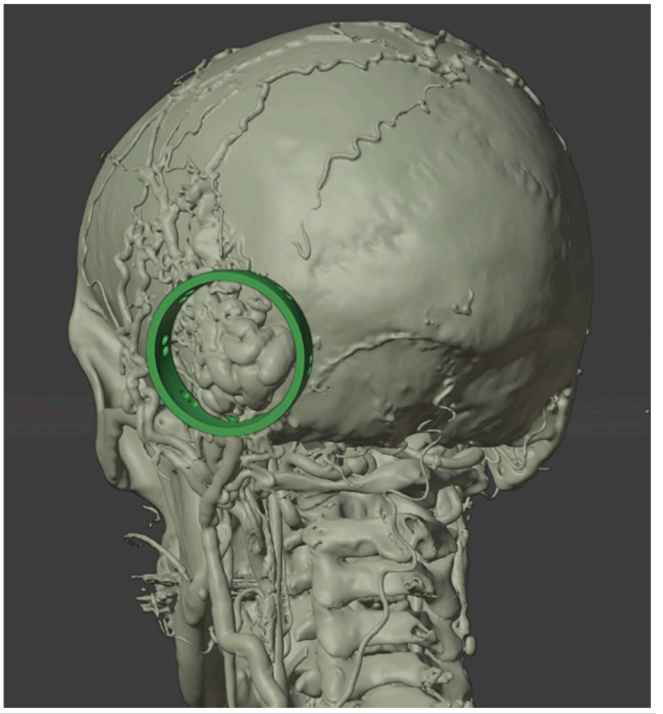

Fig 2. Posterolateral computed tomography (CT) view showing the donut-shaped device designed to enclose the arteriovenous fistula (AVF). The holes are designed to allow for fixation of the device to the head using elastic laces.

point of fistula rather than the total malformation to maximize localization of the embolic effect.

Device fabrication. The donut was fabricated using an in-house 3D printer (Anycubic Photon Mono M7 Pro, Shenzhen Anycubic Technology Co) and biocompatible resin; the designed holes in the borders were used to pass some laces to ensure a tight fit to the patient's cranial surface during the procedure.

Donut-guided embolization. The first treatment phase consisted of embolization under general anesthesia using C-arm biplane angiography. Femoral artery access was obtained with a 4F to 8F sheath solely to allow angiographic assessment throughout the procedure, while the embolization itself was performed entirely via direct puncture (18G-21G needles) targeting the fistula. PHIL, a nonadhesive and tantalum-free embolic agent, was used to avoid skin staining. Other embolic agents were not considered owing to their poorer handling during the procedure, with PHIL being regarded as the best choice for direct puncture.

During this phase, the donut-shaped device was positioned directly on the skin and firmly secured to the head with tight laces. The device was wrapped to make it more comfortable on the surface. Although the device was custom made and designed based on the patient's CT scan , the skin layer created minimal adherence discrepancies, which were eliminated with this padding (Fig 3).

The donut served to physically circumscribe the portion of the AVF containing the nidus, identified as the region intentionally selected during CAD design, so that direct puncture performed within its inner boundary would ensure that the embolic material remained confined inside that area and would not flow into the efferent vessels. Such an event could allow the material to enter cutaneous vessels, potentially causing skin ischemia. At the end of the procedure, the laces are loosened to remove the donut and to avoid prolonged application, which could damage the skin.

We confirmed through angiographic control that the embolic material did not escape beyond the boundaries of the donut.

Surgical procedure. After embolization, the intubated patient underwent surgical excision (Fig 4). This hyperselective embolization also guided surgery: the embolic cast clearly outlined the malformation, enabling easy dissection and complete removal. In this specific case, the skin overlying the fistula was removed because it was already damaged and infiltrated by the fistula, making it inseparable. The bloodless surgical field made it possible to avoid vessel ligation, and hemostasis was achieved solely with electrocautery. The defect was closed primarily, and no advancement flaps or grafts were required.

This phase is critical because embolization alone does not remove the pathology, and the risk of recurrence is high owing

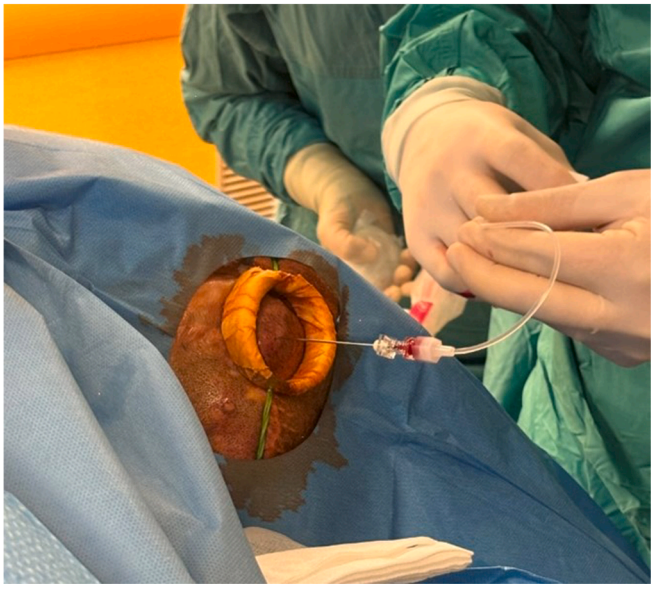

Fig 3. Direct puncture phase with the custom-made donut device.

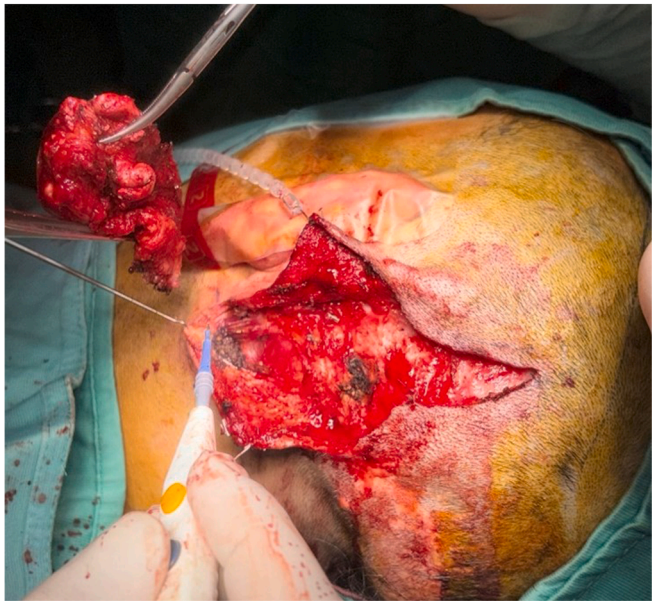

Fig 4. Intraoperative appearance.

to the inevitable resorption of the embolic material. By surgically removing the fistula, however, the risk of recurrence is eliminated, because the pathology is effectively excised.

RESULTS

The procedure was completed without complications, and the patient was discharged on postoperative day 3. Ultrasound examination at 1 month showed complete resolution of abnormal blood flow, with the swelling replaced by a well-healed linear scar. The patient reported disappearance of pulsation and bruit. A CT scan at 6 months confirmed full resolution (Fig 5). Follow-up continues.

DISCUSSION

S-AVFs are rare, usually post-traumatic or iatrogenic, presenting as pulsatile subcutaneous swellings with high bleeding risk. Treatment is challenging owing to the lack of standardized guidelines and must be tailored to the patient and operator experience. Endovascular embolization (using Onyx, coils, etc) is commonly reported,[4] although some advocate surgery alone to decrease recurrence and avoid embolization complications.[5] A combined approach—embolization plus surgical excision—offers the benefits of both techniques, typically performed days apart. However, the authors' experience suggests performing both phases on the same day, allowing the patient to undergo a single general anesthesia and benefiting from early embolization during surgery.[6] The advantages of the combined technique include a lower risk of intraoperative bleeding, which is typical of surgery alone, as well as a lower risk of recurrence, which is characteristic of embolization alone and related to the gradual resorption of the embolic material. The only precautions that operators need to take are that the device may not fully conform to the anatomy of the skull, which could prevent the embolic material from being completely confined

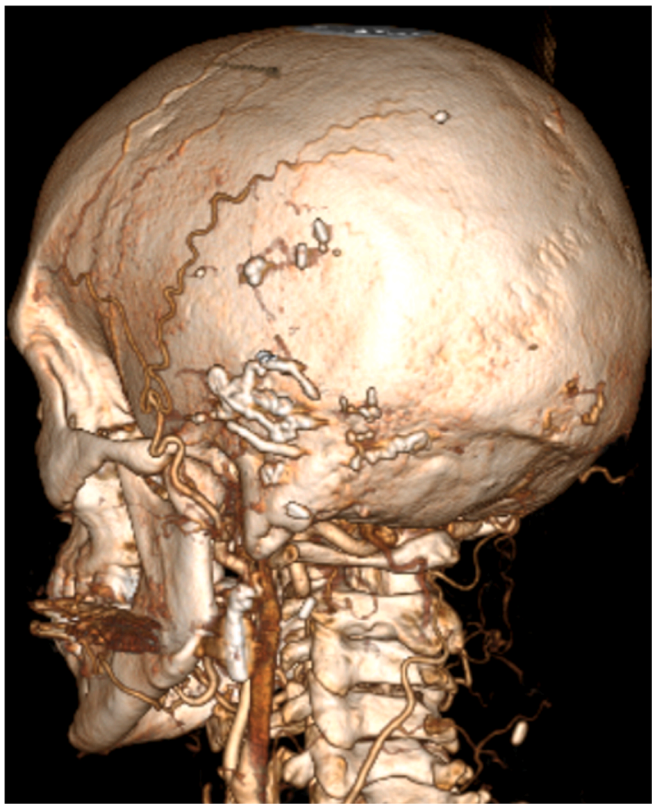

Fig 5. Postoperative computed tomography (CT) scan shows complete resolution.

within it and inadvertently cause skin necrosis, and the possibility of incomplete embolization, which could lead to bleeding during surgery.

Based on clinical and imaging findings, the patient underwent single-session embolization and surgery using a custom 3D-printed donut device, allowing targeted PHIL embolization, preventing leakage and skin necrosis. The procedure was safe, complication free, and reproducible.

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DISCLOSURES

None.

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