REVIEW

Head and Neck Arteriovenous Malformations: Clinical Manifestations and Endovascular Treatments

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Abstract:
Arteriovenous malformations (AVMs) are vascular malformations that present high-flow direct communication between the arteries and veins, not involving the capillary beds. They can be progressive and lead to various manifestations, including abnormal skin or mucosal findings, ischemia, hemorrhage, and high-output heart failure in severe cases. AVMs often involve the head and neck region. Head and neck AVMs can present region-specific clinical manifestations, angioarchitecture, and complications, especially in cosmetic appearance and ingestion, respiratory, and neuronal functions. Therefore, when planning endovascular treatment of head and neck AVMs, physicians should consider not only the treatment strategy but also the preservation of the cosmetic appearance and critical functions. Knowledge of the functional vascular anatomy as well as treatment techniques should facilitate a successful management. This review summarizes AVMs' clinical manifestations, imaging findings, treatment strategy, and complications.

Introduction

Arteriovenous malformations (AVMs) are a rare pathological entity in which the arteries and veins directly communicate, not involving the capillary beds. Basically, these vascular lesions exhibit fistulous arteriovenous communication, "nidus"-like vascular tangle, or both. AVMs can involve any organs and may present various symptoms depending on the involved lesions and their stages. The head and neck region is one of the common sites of AVM. To treat AVM, a multidisciplinary approach including surgical resection, transcatheter embolization, direct percutaneous embolization/sclerotherapy, laser coagulation, and drugs is generally considered. However, the head and neck region is characterized by complex anatomy in which the critical organs, such as the brain, cranial nerves, eyes, large vessels, and airway, are concentrated in a limited area, potentially making treatment difficult [1, 2]. For a safe and effective endovascular treatment of AVMs involving the head and neck region, knowledge of the anatomy, imaging findings, treat-

ment options, and complications is particularly important. This section outlines the findings and endovascular management of head and neck AVMs.

Clinical Manifestations of Head and Neck AVMs

In the head and neck region, various tissues and organs may be affected by AVM. Among them, the scalp, auricle, cheek, nose, lip, and mandible are particularly common locations. Furthermore, AVM can arise from any or multiple parts of organs, such as the subcutaneous tissue, submucosal tissue, muscle, and bone. Depending on the location and stage, head and neck AVM can also present various symptoms. The characteristic manifestation in the early stage of head and neck AVM is cosmetic appearance changes. When the lesion is located cutaneously, subcutaneously, or submucosally, a warmish pulsatile blush and swelling may occur. Meanwhile, AVMs adjacent to the auditory organ may generate bruit. Moreover, AVMs that appear in childhood may gradually enlarge during puberty under the effect of hormo-
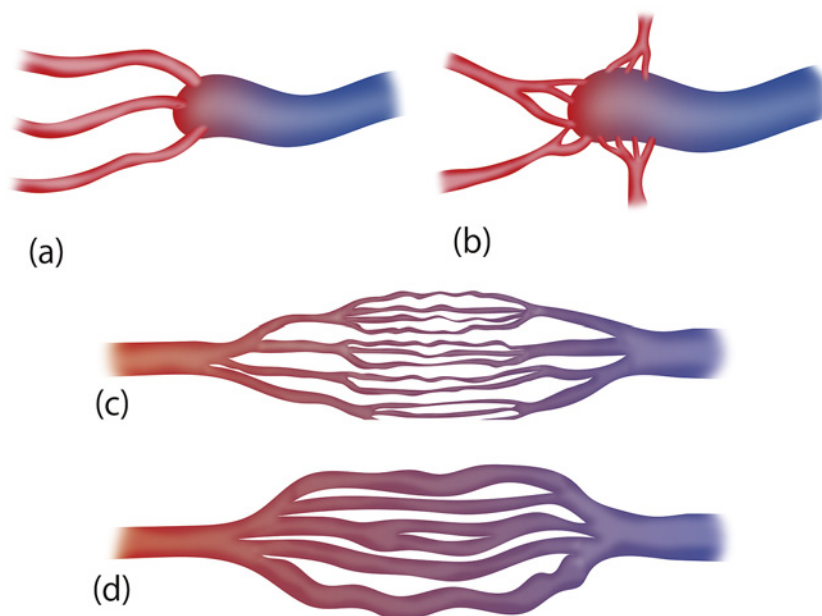
Figure 1. Schematic drawing of Cho's classification for peripheral AVMS (reprinted and modified with permission of reference 5).
a. Type I: no more than three separate arteries shunting to the initial part of the single venous component.
b. Type II: multiple arterioles shunting to the initial part of the single venous component (dominant outflow vein).
c. Type IIIa: fine multiple shunts between the arterioles and the venules presenting blush or fine striation on angiography.
d. Type IIIb: fine multiple shunts between the arterioles and the venules presenting complex vascular network on angiography.

nal change. They may recruit feeders and drainers with the involvement of surrounding tissues. If these lesions progress, more severe symptoms, such as spontaneous pain, ulceration, bleeding, functional impairment, and high-output cardiac failure, can occur. Among these, nasopharyngeal bleeding occasionally results in mortality due to the difficult hemostatic condition, severe blood loss, and/or respiratory impairment. In most cases, the therapeutic goals might be to relieve these symptoms and prevent progressive severe symptoms, rather than achieve a cure.

Classification

To standardize the evaluation of the severity and treatment strategy for AVMs, it is important to use a classification system. To evaluate the severity of extracranial AVMs, Schöbinger's classification is commonly used [3]. This classification is based on dermatological and cardiocirculatory assessment of the symptoms, with grading from stages 1 to 4. Stage 1 is the quiescent stage, in which warmness and skin blush or ultrasonographically detectable shunts appear; stage 2 is the expansive stage, in which pulsatile bruit and thrills are detected; stage 3 is the destructive stage, in which rest pain, skin ulcer, and/or bleeding occur; and stage 4 is the decompensative stage, in which high-output cardiac failure can be observed. AVMs in stage 3 or 4 are an absolute indication of treatments, whereas aggressive treatments for AVMs at

milder stages should be carefully considered. However, a previous report described that AVMs in stage 1 may progress to stage 3 in half of the cohort; this suggests that mild AVMs might be an indication for treatments to prevent progression [4].

Cho et al. classified extracranial AVMs based on the angioarchitecture to determine the appropriate endovascular and/or percutaneous approaches (**Fig. 1**) [5]. This classification comprises types I, II, IIIa, and IIIb. They defined the architecture as follows: Type I AVM shows no more than three separate arteries shunting to the initial part of the single venous component. Type II presents multiple arterioles shunting to the initial part of the single venous component. Type IIIa shows fine multiple shunts between the arterioles and venules presenting blush or fine striation. Type IIIb shows fine multiple shunts between the arterioles and venules presenting a complex vascular network. They reported that type II and IIIa AVMs presented good treatment results using a transvenous approach or direct percutaneous approach, whereas type IIIa AVMs could be treated only with transarterial embolization.

Recently, Yakes proposed a new classification based on angiographic findings, which includes the following: type I, direct connection between the artery and the vein; type IIa, multiple arterial inflows into a "nidus" with direct artery/arteriole and vein/venule connections; type IIb, AVM with a nidus draining into an aneurysmal vein; type IIIa, multiple
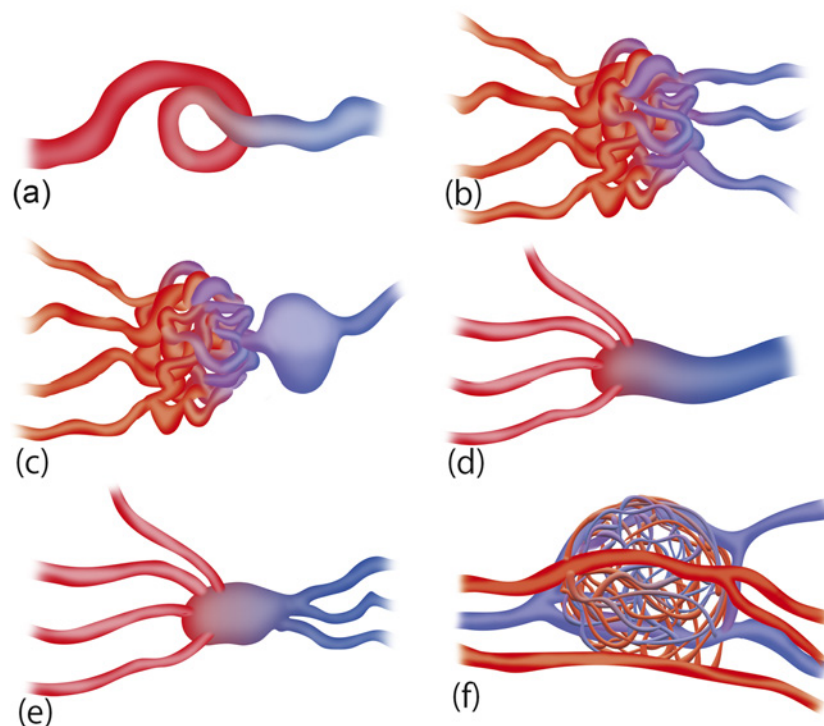
Figure 2. Schematic drawings of Yakes' classification of AVMs (reprinted and modified with permission of reference 6).

a. Type I: direct connection of the artery and vein.

b. Type IIa: multiple inflow arteries into a "nidus" with direct artery/arteriole and vein/venule connections.

c. Type IIb: AVM with a nidus draining into aneurysmal vein.

d. Type IIIa: multiple arteries/arterioles connecting micro-fistulas into the wall of an enlarged aneurysmal vein with a single outflow vein.

e. Type IIIb: multiple arteries/arterioles connecting micro-fistulas into the wall of an enlarged aneurysmal vein with multiple dilated outflow veins.

f. Type IV: innumerable, diffuse, micro-fistulous arteriolar structures shunting into innumerable venular connections.

arteries/arterioles connecting the micro-fistulas into the wall of an enlarged aneurysmal vein with a single outflow vein; type IIIB, multiple arteries/arterioles connecting the micro-fistulas into the wall of an enlarged aneurysmal vein with multiple dilated outflow veins; and type IV, innumerable, diffuse, micro-fistulous arteriolar structures shunting into innumerable venular connections (**Fig. 2**) [6, 7]. Yakes' type IIIa corresponds to Cho's type I or II, whereas Yakes' type II corresponds to Cho's type III.

Imaging Findings

Imaging modalities are essential in making a definitive diagnosis of AVMs after obtaining the medical history and physiological findings. Radiological evaluation provides important information to reveal the extent, type, and severity of lesions. Based on these findings, the treatment strategy can be evaluated.

Plain radiograph cannot depict AVMs but can identify secondary abnormal findings due to the extension of AVMs and/or a dilated feeding/draining vessel, such as soft-tissue swelling, calcification of the vessel walls and organized thrombi, bone or tooth destruction, or compression erosion. This imaging modality can be used after the treatment to follow the radio-opaque embolic materials and post-treatment secondary ossification.

Ultrasonography with Doppler is a useful imaging modality owing to its non-invasiveness and inexpensiveness. This modality is usually applied as an initial imaging test to evaluate bulky and reddish subcutaneous lesions. A dilated and tortuous vessel-like structure with arterial pulsatile waveform and color signal on Doppler ultrasonography suggests AVM, which can be differentiated from other low-flow vascular malformations [8-11]. In addition, this modality can be useful for direct percutaneous treatment when advancing the needle to the optimal segments.

CT is a useful imaging tool, thanks to its high spatial resolution and short scanning time. It can detect soft-tissue abnormalities and bony involvement. The dynamic contrast-enhanced CT is an extremely useful modality to obtain three-dimensional (3D) image data. Furthermore, with the recent advances in machine performance, we can evaluate the angioarchitecture with high spatial resolution. Despite the high image quality of 3D-CT angiography, this tool

lacks dynamic information [12, 13]. To overcome this short-coming, four dimensional (4D)-CT angiography is also available to obtain flow-dynamic and tridimensional data owing to the advantage of the recently developed high-speed scanning and wide-range detector with an optimized radiation dose and reconstruction algorithms. However, this imaging technique is generally used only for intracranial or spinal lesions without respiratory movement [14-18].

MRI is an essential modality often used for the initial radiological diagnosis of soft-tissue and bone lesions. Its major advantage is higher contrast resolution than that in other imaging modalities, without the need for radiation exposure. In this approach, AVMs can be demonstrated as tangles of flow voids contiguous with surrounding dilated vessels. This approach is also important for diagnosing the extension of the lesion into surrounding tissues as well as secondary findings, such as edema or hemorrhage. MR angiography (MRA) is also a useful imaging modality to detect the vasculature of AVMs. Conventional time-of-flight MRA has been used especially in detecting intracranial or extracranial head and neck AVMs [19, 20]; however, this approach is disadvantageous due to the lack of dynamic information, lower detectability of slow and small vessels, and prolonged scanning time. Contrast-enhanced dynamic time-resolved MRA takes advantage of the high capacity for detecting the flow dynamics of the AVMs, regardless of high-flow or low-flow shunts [21-23]. The recently developed non-contrast MRA allows us to obtain dynamic images with high temporal and spatial resolutions [24-28]. By using this scanning technique, the feeding arterial and draining venous structures can be distinguished without the use of gadolinium contrast medium.

Transcatheter angiography is a particularly useful imaging modality for detailed evaluation of the angioarchitecture of AVMs. Owing to its higher spatial and temporal resolutions compared with other modalities, angiography remains the gold standard, despite its invasiveness [29-33]. For the angiographical diagnosis of head and neck AVMs, diagnostic catheters with an ideal tip shape, such as Headhunter, John-Benson types 1 and 2, and SIMMONS, might be used for head and neck arteries with alternative femoral, brachial, or radial approaches. Head and neck AVMs may be fed by multiple and/or bilateral arteries, including the external/internal carotid and vertebral and subclavian arteries, depending on their distributions. To demonstrate the entire angioarchitecture of these lesions, all feeders should be fully catheterized, and the contrast medium should be injected at an appropriate injection rate and amount. It is sometimes difficult to evaluate the architecture of large, high-flow, and complicated AVMs by only catheterizing the main trunks, such as the external carotid artery or subclavian artery. To depict the detailed architecture for the assessment of the most appropriate treatment strategy, selective angiography with catheterization of each feeder using balloon flow control and/or 3D rotational angiography might be needed. Recent advances in the visualization of blood flow provide time-resolved 3D images that can obtain dynamic 3D data from the feeding arteries to the draining veins [34-37]. This technology has mainly been reported as a novel form of imaging of intracranial vascular lesions, but it can be useful for demonstrating the vasculature of extracranial head and neck AVMs.

Endovascular Treatment

a) Devices

i) Guiding catheter

A guiding catheter is required to access the targeted point *via* a transarterial or transvenous approach. Especially for access to cerebral or head and neck vessels, the guiding catheter needs to include support for the microcatheters, a soft tip so as not to injure the cerebral vessels, and a sufficient internal diameter to inject the contrast material and flush out the heparinized saline continuously. For an approach into tortuous access routes, an angled guiding catheter is sometimes useful.

For flow control to obtain better visualization of a high-flow lesion or achieve safe and effective embolization, a balloon guide catheter should be used. These guide catheters are equipped with a flexible compliant balloon at the tip and can thus temporarily stop the arterial flow at the proximal segment.

ii) Distal access catheter

This type of catheter was developed to support microcatheters, especially for far distal lesions with a tortuous access route, especially for the cranial vessels [38]. Distal access catheters are characterized as having a 3.2-4.2 French tip size with a flexible shaft, allowing navigation of the microcatheter far distally by supporting its shaft despite tortuous access routes (**Fig. 3**). Furthermore, a certain type of balloon catheter with a flexible and hydrophilic slippery shaft can be applied to distal access catheters concomitantly with balloon flow control (Cello 5F; Medtronic, Irvine, CA, USA).

iii) Microcatheter

Numerous types of microcatheter are currently available. They should be selected on the basis of the projected embolic materials, which require appropriate profiling of the internal diameter, active length, radio-opaque marker, chemical compatibility for the relevant solution, etc. In general, for head and neck vessels, flexible and soft designs are favorable to avoid vasospasm and prevent damage to the vessel wall. Head and neck AVMs are commonly fed by tortuous feeding arteries. These arteries can usually be approached using flow-directed floppy-type catheters with a 1.2-1.5 French tip size (**Fig. 4**).

iv) Embolic materials

For the endovascular treatment of AVMs, various embolic materials can be used. These materials comprise temporary or permanent types and particles, liquids, sclerosants, coils, and vascular plugs. Selection of the embolic agent may be directly linked to the treatment strategy regarding which segment is going to be embolized and how embolization oc-
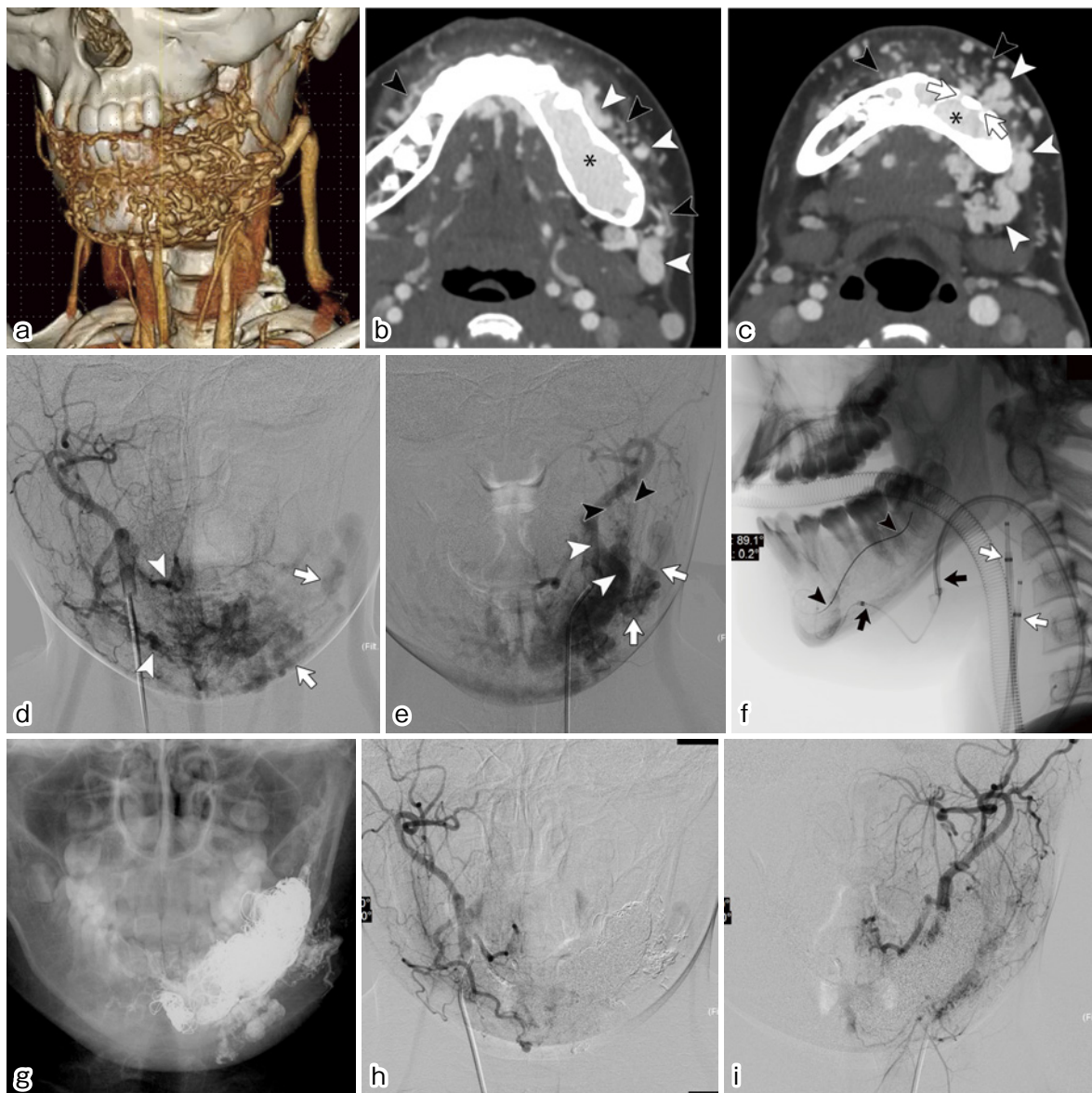
Figure 3. A girl in her 10s with mandibular AVM.

a. Left anterior oblique view of the arterial phase of 3D-CTA. Numerous feeding arteries and draining veins are found surrounding the mandibular surface.

b, c. Axial images of postcontrast CT (b, cranial; c, caudal section) show tortuous dilated feeding arteries (mental, labial, and other branches), which are given off from bilateral facial arteries (black arrowheads). The dominant outflow vein is located within the mandibular bone (asterisks). However, there is no apparent drainage vein through the mandibular foramen. Venous outflow drains into the tributaries of the facial vein (white arrowheads) *via* mental foramen and other foramina (arrows).

d, e. Frontal view of bilateral external carotid arteriogram (d, right; e, left) shows extensive mandibular AVM. This was mainly fed by bilateral facial artery (white arrowheads) and branches from the maxillary artery (buccal artery and posterior superior dental artery, black arrowheads) and was draining into the bilateral facial vein and submental vein (arrows).

f. Lateral fluorogram during transvenous approach. Despite tortuous access routes to the mandibular vein, microcatheter and micro-guidewire (arrowheads) reach the dominant outflow vein within the mandible *via* a tri-axial guidance system (black arrows, tip sizes are 4.2F, 6F, and 8F). The other two guiding catheters are navigated in the bilateral external carotid arteries (white arrows).

g. Frontal view of fluorogram after transvenous coil embolization for DOV and transarterial glue embolization for feeding arteries shows coil mass in the mandibular bone and glue cast around the mandible.

h, i. Frontal views of bilateral external carotid arteriogram (h, right; i, left) show complete disappearance of AVM.

curs.

Particles: This refers to particle-type material that can be

injected with the contrast material into the bloodstream. Acrylic microspheres (Embosphere; Merit Medical Systems,
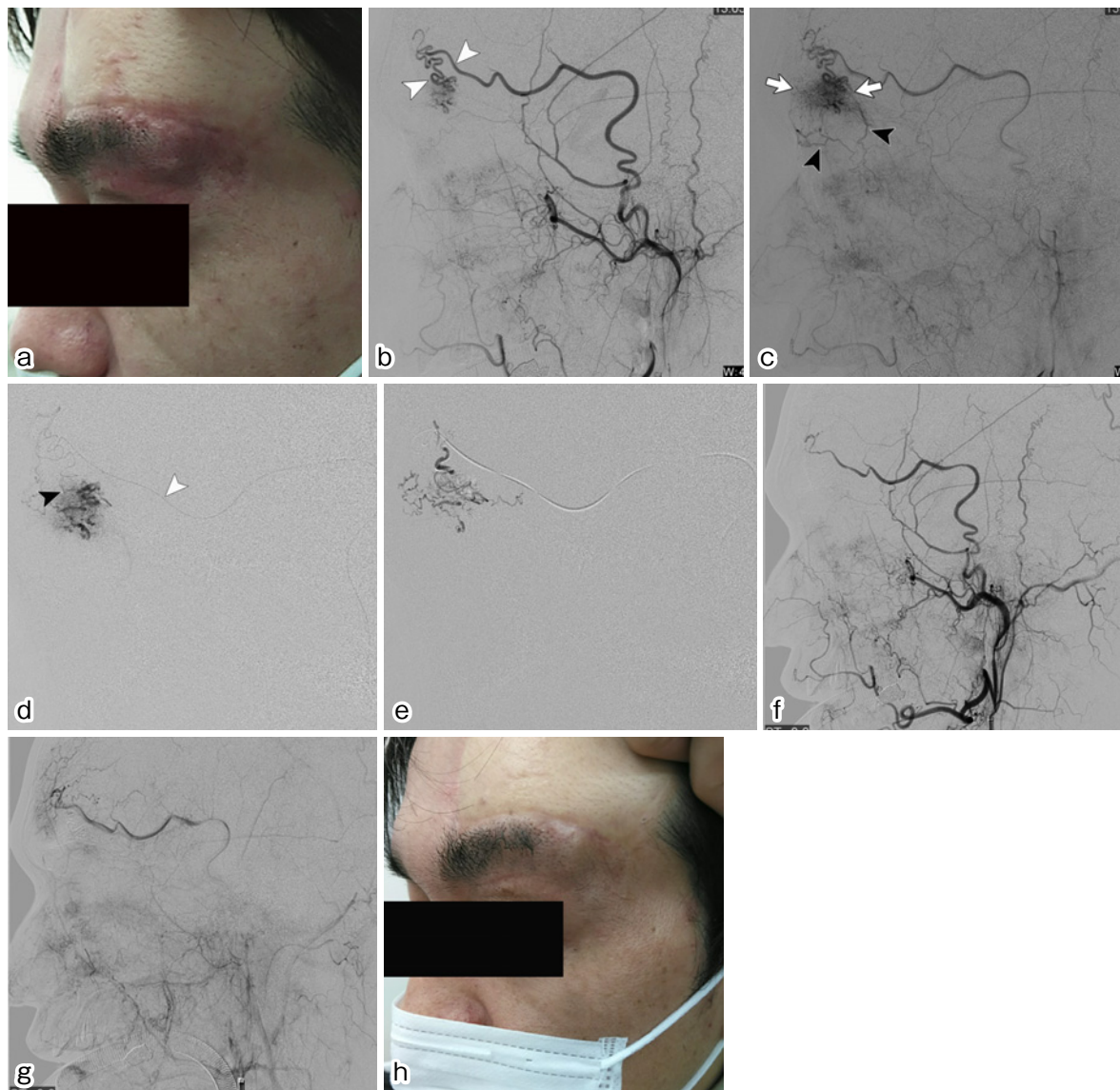
Figure 4. A man in his 40s with a history of surgical resection of facial AVM at the forehead and eyelid (Face pictures are published with comprehensive consent from patient).

a. The patient presented pulsatile swelling and erythema lateral to the eyebrow due to recurrent AVM.

b, c. Lateral view of left external arteriogram (b, early arterial phase; c, late arterial phase) shows dilated and tortuous frontal branch of the superficial temporal artery (STA) (white arrowheads), fine capillary-like vasculature (arrows), and early drainage into the medial and lateral palpebral veins (black arrowheads). This was diagnosed as recurrent-type IIIa AVM.

d. An ultrathin-type microcatheter (DeFrictor nano, 1.3F; Medicos Hirata, Tokyo, Japan) was navigated close to the shunts (black arrowhead, microcatheter tip) with the combined use of a distal access catheter (TACTICS; Technocrat, Kasuga, Japan) (white arrowhead, tip distal access catheter).

e. Low-concentration BCA-Lipiodol mixture (17%) was injected via a microcatheter. NBCA infiltrated into fine vascular networks.

f, g. Lateral view of left external arteriogram (f, early arterial phase; g, late arterial phase) shows the disappearance of recurrent AVM.

h. At 2 months after embolization, the findings included healing of the swelling and erythema without skin damage.

UT, USA) are the only permanent particles covered by the national health insurance system in Japan. The size ranges from 40 to 1,200 μm, which can be selected depending on the size of fistulas. Polyvinyl alcohol (PVA) is a permanent type of material used worldwide. Gelform (gelatin sponge particles) is also a widely used temporary type of material that can be resorbed in 4-6 weeks [39]. However, these ma-terials are not approved for the embolization of AVMs. The vascular beds of the AVMs can be embolized using particles concomitant with the thrombosis surrounding the materials; thus, there is a risk of recanalization in a long follow-up pe-riod despite the use of the permanent type. These particles might be useful for preoperative embolization.

Liquid embolic material: This type of material is fre-

quently used for the embolization of AVMs owing to its permanent embolic effect and the wide occlusivity from feeders to drainers *via* arteriovenous fistulas and perifistulous arterial anastomoses. n-Butyl-2-cyanoacrylate (NBCA) is the monomeric form of a frequently used material for the treatment of intra- and extracranial AVMs using endovascular or percutaneous approaches; this material solidifies by polymerization upon coming into contact with the ionic component of the blood [40-57]. It is characterized as an adhesive type; the adhesive effect, polymerization time, and radio-opacity can vary with the ratio of mixing with Lipiodol (Guerbet, Paris, France). It requires flushing of the microcatheter with 5% dextrose and rapid removal when reflux of the material to the catheter tip is observed to avoid catheter entrapment. Furthermore, NBCA is thought to exhibit high thrombogenicity compared with another liquid embolic material, ethylene vinyl alcohol (EVOH); thus, progressive and permanent occlusion can be achieved owing to this property [58].

EVOH is a copolymer material dissolved in dimethyl sulfoxide (DMSO) and tantalum powder. EVOH solidifies after injection *via* a microcatheter by dissipation of the DMSO solution. This material is characterized as non-adhesive, which allows slow injection and deep penetration under fluoroscopic observation. In Japan, Onyx (Medtronic, Minneapolis, MN, USA) is an approved EVOH for the embolization of intracranial AVMs and dural arteriovenous fistulas. The drawbacks of this material include the lower tendency for thrombogenicity compared with NBCA, need for a larger radiation dose due to slow injection, and higher radioopacity, which leads to an inability to visualize the surrounding vasculature compared with NBCA. In addition, this material is inadequate for the embolization of a high-flow fistulous shunt due to the risk of migration into the venous side caused by the non-adhesive and slowly solidifying character of EVOH.

Coils and vascular plugs: A metallic coil is an extremely useful embolic material to occlude vessels with a large diameter. The fistulous shunt and dominant outflow vein close to the shunt are preferable targets for coil placement. For the embolization of head and neck vessels, detachable-type microcoils are commonly used (**Fig. 5**). Recently, various types of detachable microcoil have become available, which allow for precise and tight placement of coils in the targeted vessels. The Amplatzer Vascular Plug (AVP: St. Jude Medical, Plymouth, MN, USA) is designed to rapidly occlude medium-sized or large extracranial vessels. However, the large and stiff profile of the delivery system is not preferable for head and neck lesions. Some reports of embolization for limited fistulous shunts have been published [59, 60]. The metallic materials in the form of coils and AVPs persist as masses after treatment; thus, the targeted vessels should be carefully selected to prevent cosmetic issues or discomfort, especially in the head and neck region.

Sclerosant: Absolute ethanol is a frequently used sclerosant for extracranial AVMs owing to the strong thrombogenicity caused by endothelial damage. This sclerosant may lead to tissue necrosis when injected into the normal capillary bed. Therefore, it should be injected *via* a microcatheter or punctured needle advanced close to the shunting vessels. Polidocanol is another synthetic alcohol used as a sclerosant. This material is often used as foam ("polidocanol foam") by mixing with contrast medium and CO_2 gas or air. The thrombogenic effect is mild compared with that for absolute ethanol; thus, polidocanol is generally used for the treatment of superficial and slow-flow lesions.

b) Treatment strategy and results

Endovascular treatments for head and neck AVMs have been developed based on the treatments for intracranial AVMs and AVFs. AVMs may exhibit various types of angioarchitecture, as described in the previous section. Most AVM types have multiple arteriovenous fistulas fed by multiple feeding arteries. A successful endovascular treatment can be achieved by efficiently obliterating the shunted points. Transarterial embolization at too proximal a location may result in not only incomplete obliteration but also loss of an access route for subsequent treatments, whereas transvenous embolization at too proximal a location may lead to ineffective treatment and pressure elevation in the shunted draining vein, which may cause edema or hemorrhage. To optimize obliteration of the shunting points, transarterial and/or transvenous embolization with appropriate embolic materials should be considered (**Fig. 5**).

Cho et al. reported effective treatment strategies based on angiographic classifications, including an endovascular or percutaneous approach, or their combination [5]. However, percutaneous direct approaches are often difficult to employ for head and neck AVMs due to the complex anatomy of this region and the presence of critical neurovascular and other tissues. However, especially for palliative partial embolization, direct puncture embolization is sometimes a useful option to obliterate superficially located lesions, such as AVMs located in the scalp, oral cavity, or other subcutaneous regions (**Fig. 6**) [61, 62]. For high-flow and large AVMs, direct puncture embolization might be effective when combined with flow control by a balloon catheter and/ or compression devices [63]. Type IIIa AVMs (or IIIa combined with other types) are often seen in head and neck lesions. For this type, Cho et al. recommended transarterial embolization [5]. To achieve a better embolization effect, slow (prolonged) injection with penetration to draining veins as well as shunt points using low-concentration NBCA should be performed [64]. When attempting this injection technique, extreme care should be taken not to cause catheter entrapment due to excessive backflow. For type II AVMs, percutaneous or transvenous coil embolization combined with percutaneous sclerotherapy is recommended [5]. This type is often observed in maxillo-mandibular AVMs draining into the maxillary or mandibular vein, which function as the dominant outflow veins [65, 66]. In these AVMs, the dominant outflow veins lie in the maxillary mandibular bone; thus, packing mainly with metallic coils through transvenous or direct percutaneous is effective.
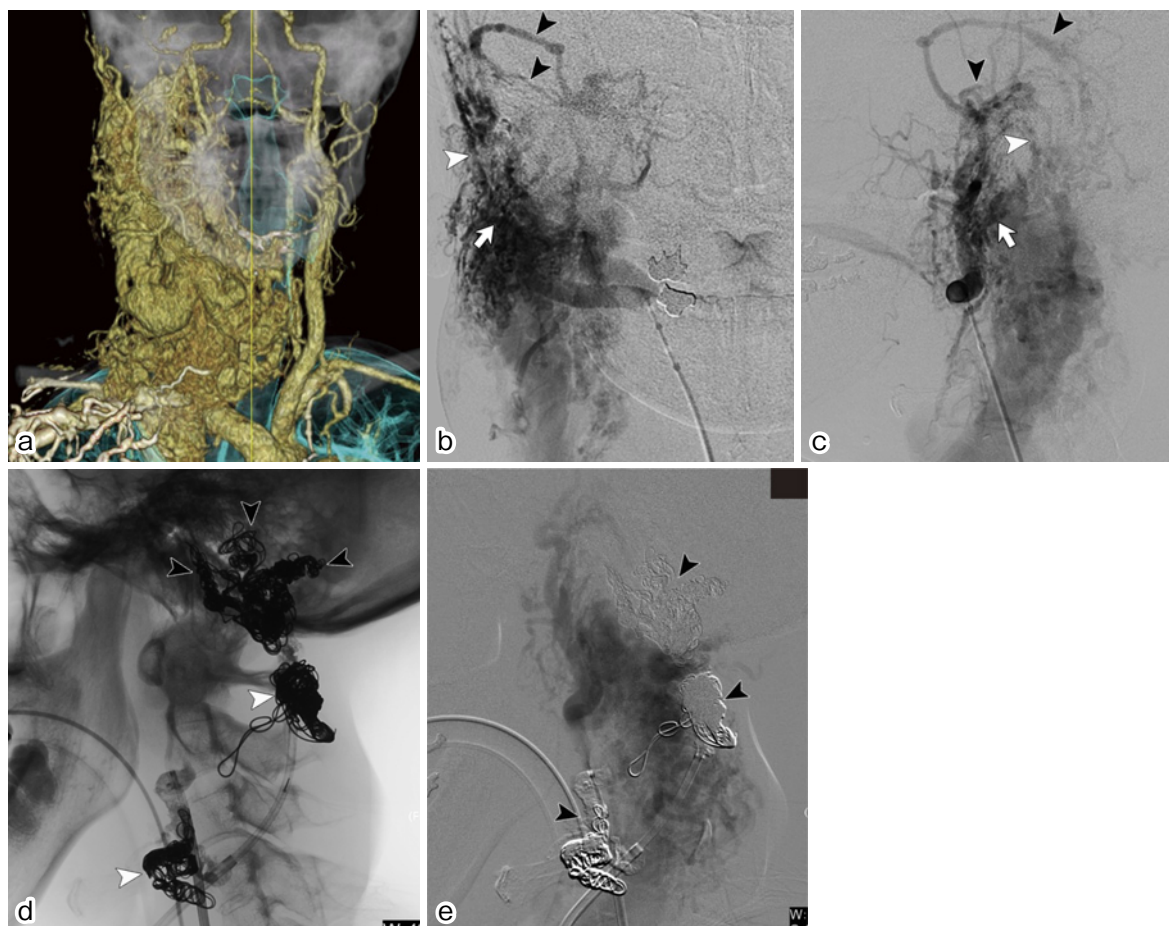
Figure 5. A woman in her 50s with right cervical AVM demonstrating cosmetic change and high-output heart failure (Schöbinger stage IV).

a. Volume rendering image of CT angiography shows giant right cervical AVM.

b, c. Right external carotid arteriogram (b, frontal view; c, lateral view) shows giant AVM occupying the subtemporal and lateral cervical parts. The component at the right upper cervical segment was mainly fed by the posterior convexity branch and the petrosal branch of the middle meningeal artery (black arrowheads), posterior auricular artery (white arrowheads), and occipital artery (white arrows). These arteries have potential anastomoses with intracranial arteries.

d. Lateral view of fluorogram after transvenous embolization. Because transarterial embolization had a risk of ischemic complication of facial nerve arcade, transvenous coil embolization for the upper cervical segment of outflow veins (black arrowheads) and fistulous high-flow shunts (white arrowheads) were performed using a dual catheter method. NBCA was concurrently used for embolization of proximal fistulous shunt.

e. External carotid arteriogram shows flow reduction of AVM at the embolized segment (arrowheads).

Varying results of embolization have been reported. Regarding head and neck AVMs, because the location, stage, angioarchitecture, and treatment strategies and difficulties significantly vary, it is difficult to discuss the treatment results definitively. Liu et al. analyzed their treatment results on a case series of extracranial AVMs in the head and neck region [4]. In their report, the overall recurrence rate of cases with embolization was only 98%, whereas the rate of cases with combined embolization and resection was 21% in stage I and 81% overall. Over the course of the decades since the case series, the advancement of devices, imaging quality, and treatment techniques should have improved the treatment results, even for treatment with embolization alone.

Complications and Management

Ischemic necrosis of the skin and mucosa is the most common complication due to cutaneous and mucosal ischemia. This complication commonly occurs when using a sclerosant, with a reported frequency of around 60% [67]. This event is dependent on the injection volume and speed, as well as the targeted vessel. Therefore, these factors should be carefully monitored when attempting to use a sclerosant for the AVMs beneath the skin and mucosa. However, this complication may also occur when using other embolic materials, especially liquid embolic material. Operators should avoid embolization that may lead to wide-ranging occlusion of the normal vasculature, such as the wedged, prolonged, and large-volume injection of liquid embolic material into fine normal vascular beds. When the cast, liquid embolic
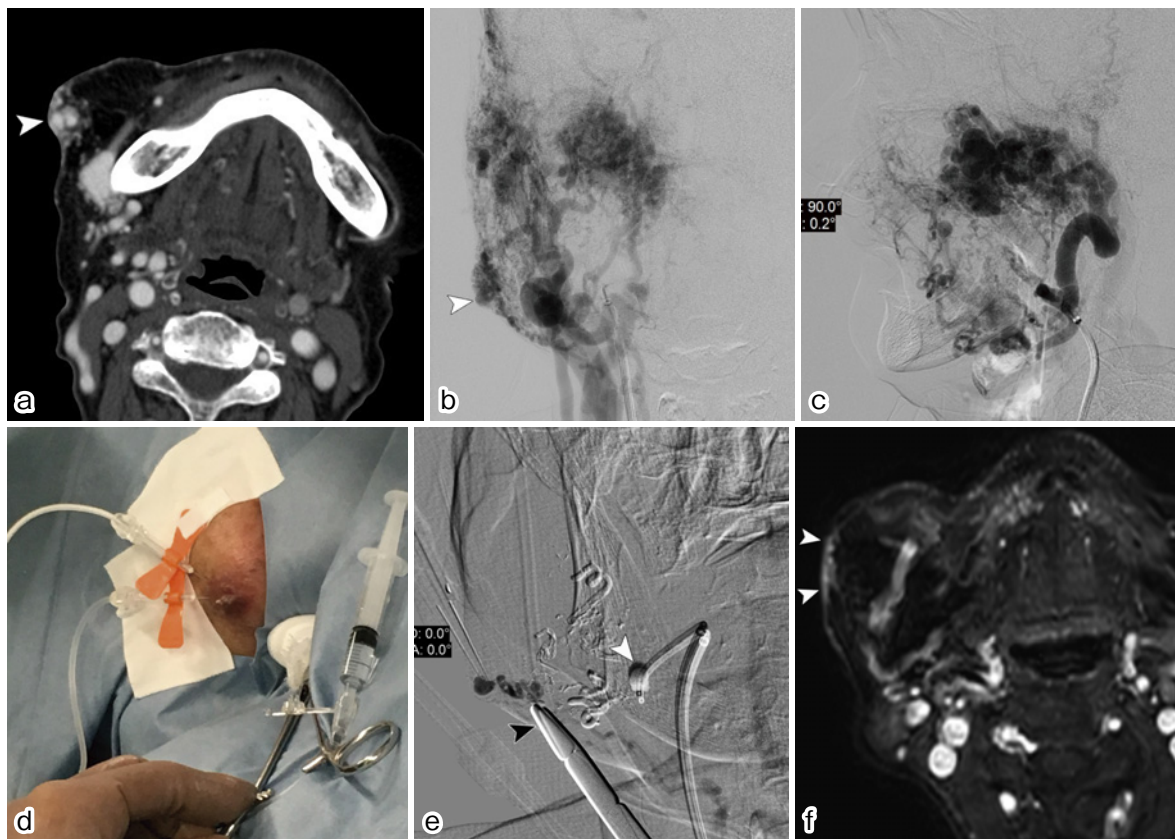
Figure 6. A woman in her 80s with maxillary and cheek AVM presenting cheek bleeding and receipt of blood transfusion.

a. Postcontrast CT shows maxillary and cheek AVM. Subcutaneous varices were detected at the right cheek (arrowhead).

b, c. Right external carotid arteriogram (b, frontal; c, lateral view) shows type IIIa AVMs fed by branches coming off from the maxillary and facial arteries with subcutaneous varices (b, arrowhead).

d. Initially, transarterial glue embolization was attempted, but it was unsuccessful due to proximal occlusion. Subsequently, direct puncture embolization was performed. Subcutaneous varix was punctured using 25-gauge butterfly needles.

e. Polidocanol foam (3% polidocanol mixed with air and contrast medium) was injected under balloon flow control of the facial artery (white arrowhead) and manual compression of the draining vein (black arrowhead). Varices and draining veins were filled with polidocanol foam.

f. Postcontrast MRI 1 month after treatment shows the disappearance of subcutaneous varices with scar formation (arrowhead).

material, or coil mass is placed beneath the skin or mucosal layer, there is a risk that these materials will be exposed through the necrotic skin, mucosa, and fragile vessel wall [68-71]. The exposure of these materials may lead to infectious complications.

Hemolysis, vasospasm of pulmonary vessels, and cardiocirculatory insufficiency can develop due to the use of absolute ethanol. To avoid these risks, the dose of one injection should be less than 0.14 mL/kg, and the total dose should be less than 0.5 mL/kg or 30 mL [72]. Monitoring of the pulmonary artery during ethanol injection is also effective [73].

Neurological ischemic complications can be caused by migration of the embolic materials into the cerebral arteries or the vessel supplying the cranial nerves, the vasa nervorum. This may lead to mortality or severe neurological deficit. To prevent this, especially in embolization with liquid embolic material, meticulous attention should be paid to the angiographic findings demonstrating the neural arteries. However, the anastomotic channels between the target arteries and the branches coming off from the internal carotid, vertebrobasilar, or ophthalmic arteries are not always visualized on conventional angiography. The vasa nervorum is also a fine vessel that is difficult to identify. These critical arteries coming off from the relevant feeding arteries may be obscured due to a high-flow shunt. Therefore, it is important to have sufficient knowledge about the functional anatomy of the head and neck arteries having anastomotic channels with cerebral arteries and the vasa nervorum, for which the injection of liquid embolic material or small-sized particles is contraindicated (**Fig. 7**) [74-77]. When it is uncertain for the operators that the targeted artery does not give off the anastomotic branches with the intracranial and orbital arteries or the vasa nervorum, the injection should be avoided, or
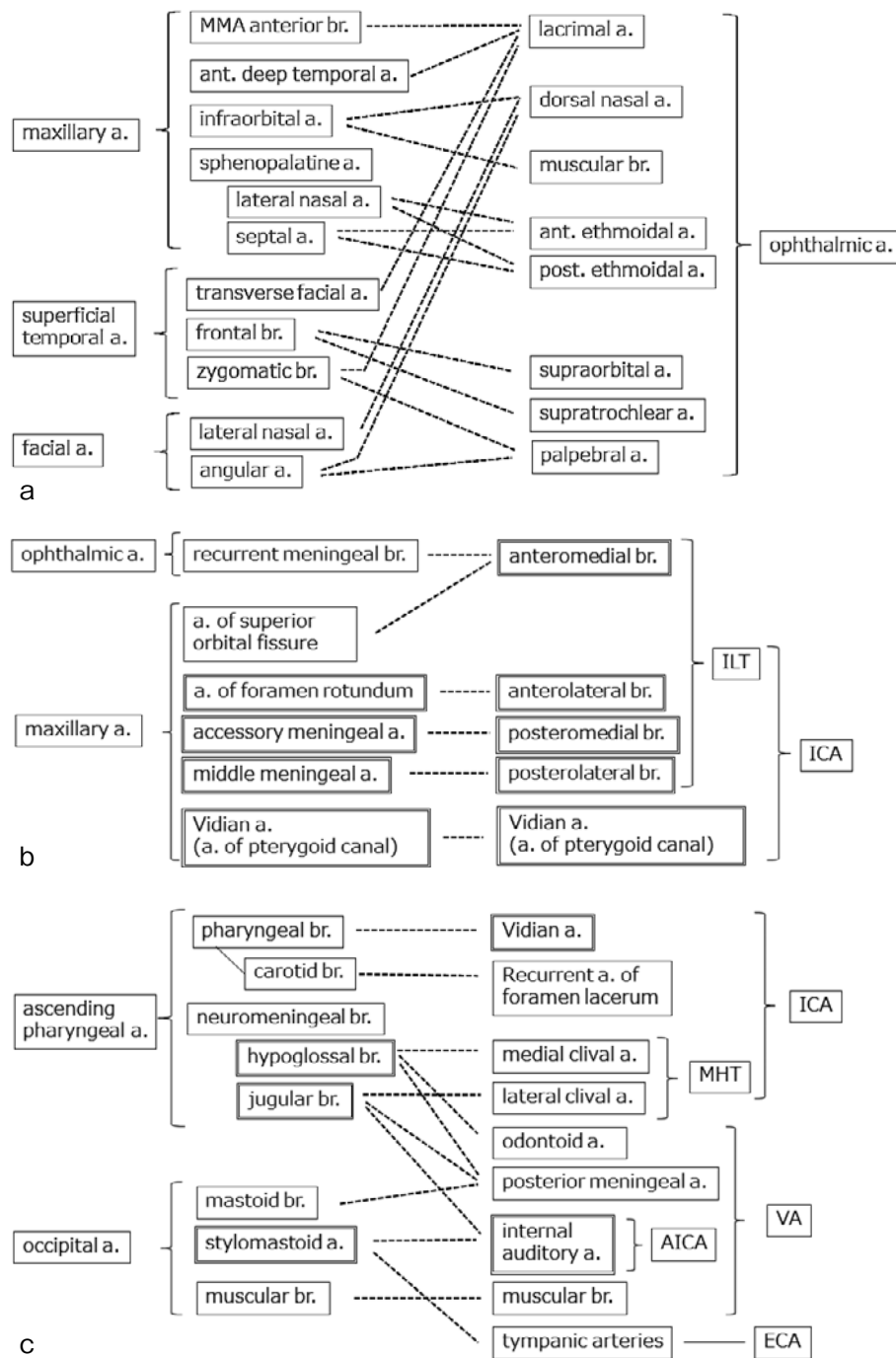
Figure 7. Diagrams showing potential anastomoses between the extracranial arteries and intracranial/ophthalmic arteries. Artery circumscribed by a double line is the vasa nervorum for nerves parallel to the artery.

 (ICA, internal carotid artery; ILT, inferolateral trunk; MHT, meningohypophyseal trunk; VA, vertebral artery; AICA, anterior inferior cerebellar artery; ECA, external carotid artery)

a. Paraorbital anastomoses between the extracranial and ophthalmic arteries.

b. Paracavernous anastomoses between the extracranial and intracranial arteries.

c. Transpetrosal and transoccipital anastomoses between the extracranial and intracranial arteries.

change of the target should be considered.

Conclusion

Endovascular treatment for head and neck AVMs is still challenging. For a safe and effective treatment, detailed as-sessment of the angioarchitecture and appropriate setting of a treatment endpoint are crucial. Appropriate selection of an approach route and devices is also necessary. Device selection and knowledge of device properties are also important. Furthermore, the risk of complications and the optimal way of managing them if they arise should be fully considered.

Finally, knowledge about the functional anatomy of head and neck vessels is essential.

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Author Contribution: ST, NT, MK, and TA were involved in the study design and data interpretation. AK, TK, and MS were involved in the data analysis. All authors critically revised the report, commented on the drafts of the manuscript, and approved the final report.
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