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REVIEW ARTICLE

Imaging of vascular anomalies of the aorta and vessels of the head and neck

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Summary

This review article aims to present the most common vascular anomalies of the head and neck arteries, detailing their clinical presentations, the diagnostic advantages of current imaging modalities, and the selection of appropriate therapeutic interventions. Vascular malformations result from localized errors in the development of blood and lymphatic vessels, leading to the formation of abnormal structures before birth. They typically grow proportionally with the child, though they may occasionally undergo rapid expansion. Vascular malformations are classified based on their hemodynamic characteristics into two major categories: slow-flow anomalies (comprising capillary, lymphatic, and venous malformations) and fast-flow anomalies (arteriovenous and arterial malformations). The incidence of arteriovenous malformations (AVMs) is increasing; many remain clinically asymptomatic, though approximately 12% are symptomatic. In cases involving hemorrhage, the mortality rate is 10–15%, with morbidity ranging from 30% to 50%. There is no gender predilection. Computed Tomographic Angiography (CTA) and Magnetic Resonance Imaging (MRI) are essential for therapeutic planning and risk assessment across surgical, endovascular, and radiological interventions. These modalities allow for the visualization of complications such as hemorrhage, stroke, and cerebral atrophy. Furthermore, magnetic resonance imaging is critical for assessing the reduction of the nidus size, the extent of post-therapeutic edema, and the presence of radiation necrosis within the treatment field. While surgery remains the primary definitive treatment, embolization has become a significant therapeutic component in recent years.

Keywords: arterial-venous malformations, computed tomographic angiography, magnetic resonance imaging, aneurysm, and venous dysplasia.

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INTRODUCTION

Modern imaging techniques, coupled with advances in stents and embolic materials, offer significant opportunities to improve the quality of life for patients with arteriovenous malformations (AVMs) (1). Accurate diagnosis and timely adherence to medical guidelines may preclude the need for surgery in certain individuals. This often involves lifestyle modifications and pharmacological interventions to control disease progression, while interventional procedures are reserved for addressing complex malformations (2,3).

The spectrum of cerebral malformations ranges from incidental findings with low risk of complications (such as venous angiomas (DVAs) or cavernomas) to conditions with possible fatal outcomes like high-risk hemorrhage (such as dural arteriovenous fistulas (DAVFs) or arteriovenous malformations (AVMs)) (3). Although rare, a primary factor in non-traumatic intracranial hemorrhage among youngsters represents vascular anomalies (4,5). The commonness of these anomalies varies significantly, ranging from 0.1% for DAVFs to as high as 25% for DVAs, according to autopsy studies (5). This review aims to present the most common vascular anomalies of the head and neck, detailing their clinical presentations, the diagnostic advantages of current imaging modalities, and the selection of appropriate therapeutic interventions, thereby reducing potential causes of morbidity and mortality.

MATERIAL AND METHODS

Our research involved searching the PUBMED database to select studies from 2005 to September 2025. The literature search was performed without restriction on study selection using the following keywords: "arterial-venous malformations", "computerized tomography", "aneurysm", "venous dysplasia", and "therapy". Important data were obtained from publications such as review papers, references from published manuscripts, and case studies. At the end, the data were critically analyzed and presented in the present paper.

Imaging Modalities

The imaging modality to choose depends on lesion position, patient age, and local expertise. Incidental findings of vascular anomalies can be initially detected on screening scans (6,7). The advent of multidetector computed tomography (MDCT) and the rapid evolution of CT angiography (CTA) have largely supplanted catheter-based angiography as a primary diagnostic method (7). The main reason is that CTA offers diagnostic sensitivity comparable to that of invasive procedures, providing anatomical information that catheterization often cannot (8). Currently, CTA of the vessels and aorta is the modality of choice for preoperative evaluation (8). Digital subtraction angiography (DSA) remains the "gold standard" for the detection and treatment of pathologically altered blood vessels. Additionally, recent advancements in magnetic resonance imaging (MRI) have provided unique insights into vascular conditions and have become instrumental in post-procedural patient assessment following embolization (9,10).

The development of computed tomography (CT) for medical purposes began in the 1960s (10). First-generation tomographs used a single detector that moved along a linear path, but second-generation tomographs enabled this development through advancements in processor technology and operational speeds (11,12). A significant refinement of the third generation was the introduction of continuous rotation of the tube and detector assembly, along with continuous longitudinal patient movement. The fourth generation of CT scanners differed in the mechanical construction of the tube and detector: the patient was positioned at the center of a detector ring, while the X-ray tube rotated within a smaller-diameter circle (13). Since 1990, continuous tube rotation and the construction of static rings have reduced scan times to 0.3 seconds. The introduction of multidetector computed tomography (MDCT) began in 1998. into clinical practice has enabled rapid, comprehensive, and precise examinations of the aorta and vessels using 32-row and, later, 64-row systems (14,15). With more detector rows, the anatomical coverage area can exceed 50 cm, enabling extensive examinations in a fraction of a second. In a broad sense, angiography is defined as the radiographic imaging of blood vessels filled with a contrast agent, encompassing arteriography, venography, and specialized procedures such as aortography and cavography. Today, the pathology diagnosed via MDCT aortography includes aortic wall and branches atherosclerosis, aortitis, congenital anomalies, penetrating atherosclerotic ulcers (PAU), infections, aneurysms, dissections, fistulas, ruptures, and endoleaks (following stent-graft placement) (16,17).

Most significantly, MDCT aortography provides distinct advantages over catheter angiography by enabling rapid, non-invasive, volumetric imaging and diagnosing pathologies at earlier stages (18). It allows for an accurate evaluation of the degree of wall calcification, atherosclerotic burden, and the extent of its distribution (18). The method facilitates the rapid and precise detection of aneurysms, including their type and propagation, as well as all necessary measurements: aneurysm length and neck, sac width, the circulating lumen, and the extent of any existing thrombus (18). In cases of aortic dissection, MDCT is essential for determining the dissection's origin, extent, and entry/re-entry sites. It distinguishes between the true and false lumina and identifies branch vessel origins, which may have significant clinical repercussions for the structures and organs they vascularize (18,19). MDCT enables comprehensive visualization of the aorta

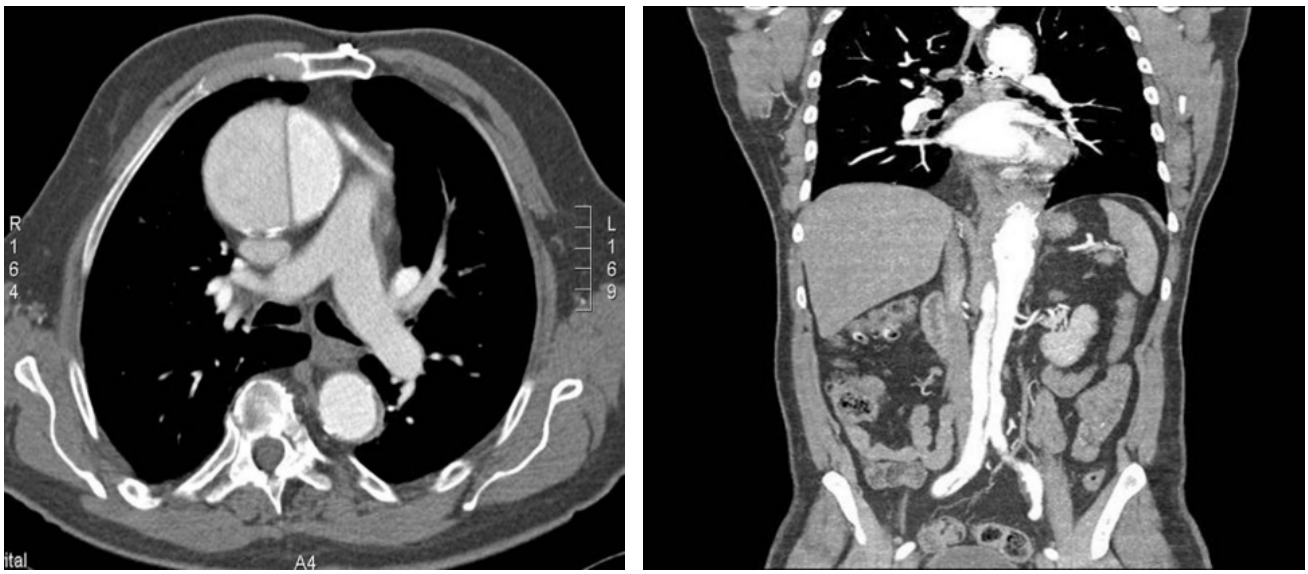

Figure 1. MD CT aortography: a) axial section of abdominal aortic dissection b) coronal section of abdominal aorta dissection. Authors obtained written informed permission to publish these images in scientific/medical journal.

across multiple planes, including axial, coronal, and sagittal planes, as well as curved reformations, multiplanar 3D reconstructions, and Volume Rendering (VR) images (20). The examination protocol typically involves both non-contrast and contrast-enhanced phases; the resulting images possess exceptionally high spatial resolution as demonstrated in **Figure 1**. The non-contrast phase is used to assess the degree of aortic wall calcification, identify intramural hematomas, and detect changes in vessel caliber (20,21). Contrast-enhanced phase is essential for characterizing aortic caliber changes, identifying aneurysm types, and detecting mural thrombi, ulcers, or PAUs (20). Additionally, it is used to evaluate stent-graft positioning and detect potential endoleaks (21).

The primary limitations of MDCT aortography include exposure to ionizing radiation, the risks of allergic reactions to contrast media, and contrast-induced nephropathy (particularly in patients with impaired renal function) (22). Additional challenges include motion artifacts due to tachycardia or obesity, the potential inability to detect certain conditions (such as endoleaks following EVAR), increased image noise with thinner collimation, and the requirement for extensive radiological interpretation of a vast number of images (22). Limitations related to hypersensitivity to iodinated contrast media or their components are addressed through adequate pre-procedural preparation (23). Patients with impaired renal function are scanned in consultation with an allergist and a nephrologist (24). Magnetic resonance imaging (MRI) is sensitive in localizing AVM nidus in the brain and the associated draining vein or distal bleeding (25). Typical signs of rapid flow in AVM include serpiginous and tubular flow voids on both T1- and T2-weighted images, most evident on T2-weighted images (25). The previous hemorrhage, adjacent brain edema, and atrophy are possible deteriorations detected using this imaging modality. The effects of radiosurgery may be evident on MRI, including regression of the nidus volume, post-therapy edema, and radiation necrosis (26).

Summary: MDCT aortography allows simultaneous visualization of the vessel and the surrounding perivascular structures and provides detailed insight into the structure of the vascular wall, assessing its continuity, thickness, and density. MDCT evaluation of the aorta serves various clinical functions, including screening, preoperative planning, and follow-up.

Clinical Applications

Common Pathology of the Aorta

Acute aortic syndrome (AAS) serves as a common denominator for a group of life-threatening emergencies that necessitate rapid, precise diagnosis and immediate clinical intervention (27). This spectrum of pathology includes aortic dissection, intramural hematoma, and penetrating atherosclerotic ulcer. Consequently, MDCT has become the gold standard for diagnosing acute aortic syndrome (27).

Aortic Dissection

Aortic dissection accounts for 80–90% of all acute aortic syndromes. The pathophysiological hallmark is a lesion of the tunica media (secondary degeneration or cystic medial necrosis), leading to loss of arterial wall elasticity and compliance (28). This condition is frequently associated with genetic mutations leading to congenital weakness or progressive degeneration of elastin and collagen (e.g., Marfan, Ehlers-Danlos, Turner, and Loeys-Dietz syndromes) (28). However, similar degenerative changes may occur in their absence. Dissection typically originates in the ascending aorta along the right lateral wall, or in the distal descending part immediately after the exit

of the left subclavian artery. Dissections are primarily classified by anatomical extent (using the DeBakey or Stanford systems) and clinical stage (acute, subacute, or chronic) (29). The most common clinical presentation is the sudden onset of sharp, tearing pain in the chest, back, or neck, often accompanied by diaphoresis, nausea, syncope, or occasionally loss of consciousness.

MDCT is the initial diagnostic modality of choice for suspected aortic dissection compared with MRI, transesophageal echocardiography, and conventional aortography (29). To eliminate motion artifacts and prevent false-positive findings, ECG-gated acquisition is essential. The scan field should encompass the entire aorta through to the iliac arteries, typically utilizing a multiphasic protocol (non-contrast, arterial, and venous phases) (30). A typical MDCT finding includes an intimomedial flap separating the true and false lumina, along with an entry point with one or more re-entry sites (30). The true lumen is typically smaller and more intensely opacified by contrast media during the early arterial phase. The false lumen is most often crescent-shaped, with sharp angles relative to the aortic wall (beak sign) (31). Occasionally, in cases of an incomplete intimomedial flap, a web-like appearance is visible (cobweb sign). It is essential to assess whether the supra-aortic and visceral branches originate from the true, false, or both lumina (31). The intimomedial rupture sign is present at the level of the entry point, characterized by a protrusion of the flap from the true toward the false lumen, which aids in lumen differentiation (32). As a dissection progresses, intussusception of the intimomedial flap between the true and false lumina may occur (windsock appearance), causing the true lumen to take on a cylindrical shape. Due to complex flap delamination, more than two lumina may sometimes be observed (Mercedes-Benz sign) (32,33). Differential diagnostic challenges include embryological anomalies (sinuses, ducts, or diverticula). Minor ruptures or hematomas confined by adjacent structures (sleeve hematomas), particularly in Type A dissections, may mimic a segmental pulmonary embolism (32).

Penetrating Aortic Ulcer (PAU)

A penetrating aortic ulcer (PAU) is defined as an ulceration at the base of an aortic atherosclerotic plaque, with subsequent penetration through the intima, specifically the internal elastic lamina, into the media (32). PAU is frequently associated with dissection or IMH. Multiple PAUs are common, especially in the presence of diffuse atherosclerotic disease, and vary in diameter and depth. They often occur in the descending and abdominal aorta, less frequently in the aortic arch, while PAUs of the ascending aorta are rare. They account for up to 7% of all acute aortic syndromes and are more prevalent in men over the age of 70, hypertensive patients, and smokers (33). Potential complications of PAU include the development of IMH, dissection, and/or adventitial pseudoaneurysm, as well as transmural rupture (33). According to available literature, the risk of rupture is as high as 40% (34). On MDCT, a PAU typically manifests as extraluminal contrast pooling in direct communication with the aortic lumen, accompanied by an adventitial defect. Coarse calcifications of the aortic wall are also frequently present (34). It is necessary to differentiate these ulcers from pseudoaneurysms and saccular aortic aneurysms. Some authors describe "ulcer-like projections" and "intramural blood pools" as distinct entities, which are occasionally observed in patients with IMH and aortic dissection (33,34). These are believed to be caused by increased intraluminal pressure and shear stress, appearing as small pools of contrast media within the hematoma or a thrombosed false lumen (typically measuring less than 3 mm in diameter).

Intramural Hematoma (IMH)

Intramural hematoma (IMH) is generally considered to result from the spontaneous rupture of the vasa vasorum, leading to hemorrhage within the aortic media in the absence of an intimal lesion (34). In addition to spontaneous occurrences, IMHs may develop as a consequence of mechanical trauma (e.g., motor vehicle accidents) or iatrogenic injury (e.g., rough handling during coronary angiography, etc.) (35). For accurate diagnosis, MDCT should be performed with ECG-gating, with a non-contrast phase performed before contrast media administration. On non-contrast scans, IMH appears as a hyperdense region (40–70 HU), typically with smooth and regular contours, exhibiting a crescentic or ring-like shape and a thickness usually exceeding 5 mm (35). Neither an intimomedial flap nor internal blood flow is visible within the hematoma. Following contrast administration, the hematoma density remains unchanged (36).

The primary diagnostic challenge lies in differentiating IMH from aortic dissection with (in)complete thrombosis of one of the lumina (36). If a delayed (venous) phase were performed, faint opacification of one of the lumina could be expected in cases of dissection. Furthermore, unlike dissection, which often exhibits a spiral propagation pattern, IMH typically extends linearly or in a circular pattern (36). Aortitis can also pose a diagnostic challenge, especially when it extends along the entire aorta. In aortitis, the periaortic muff is typically irregular, poorly demarcated, and frequently heterodense (36,37).

AAS is an increasingly prevalent emergency condition that radiologists frequently encounter in clinical practice, and aortic dissection represents a life-threatening crisis, most commonly affecting individuals in their sixth and seventh decades who may otherwise appear healthy. Precise interpretation of MDCT findings, in concert with the patient's clinical presentation, is paramount in determining the therapeutic course. Patients with AAS

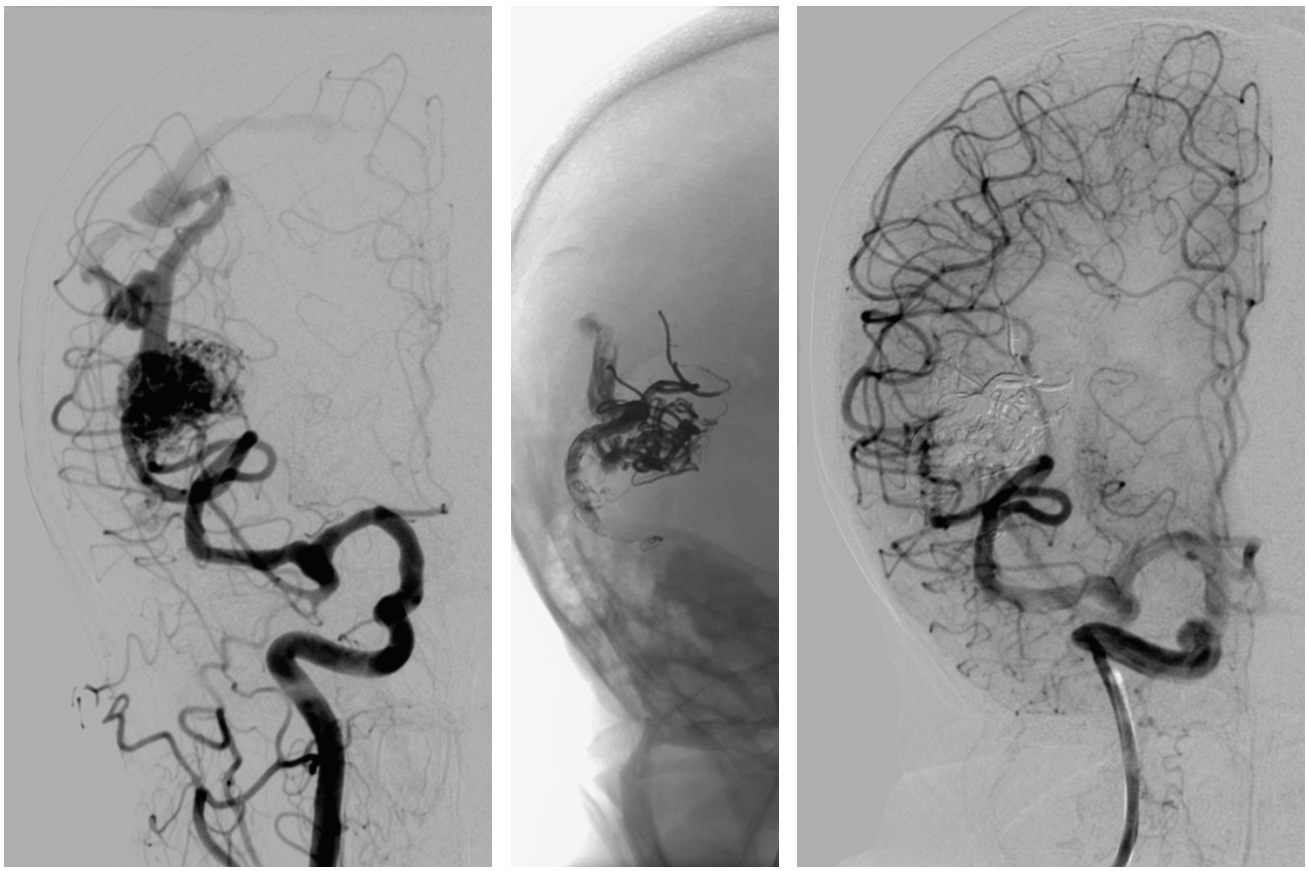

Figure 2. 33 years old woman. Non-bleeding temporoparietal pial AVM, before treatment and after complete obliteration with liquid embolization agent. Authors obtained written informed permission to publish these images in scientific/medical journal.

undergoing pharmaceutical management require rigorous surveillance via periodic MDCT examinations, considering the tendency for aortic dilation and the potential development of complications.

Vascular Malformations of the brain and spine

a) Cerebral arteriovenous malformations (AVMs) are primarily considered congenital anomalies (38). However, some theories suggest they may also result from an angiopathy response occurring after an ischemic stroke or hemorrhagic event as primary contributing factors. Multiple classifications exist, based either on the hemodynamics of the anomalies regarding the presence/ absence of arteriovenous connections (either high-flow or slow-flow) or on the type of abnormal vessels (arterial, capillary, or venous) (38). Characteristic features include the presence of a network of small abnormal vessels forming a nidus and the presence of early venous drainage into cortical veins or dural venous sinuses (38). They most commonly manifest with intracerebral hemorrhage (41%–79%), headache (9%–70%), seizures (11%–33%), and in 20% of cases, other focal neurological deficits (39-41). These symptoms may result from hemorrhage, edema, or the so-called "steal phenomenon" – hypoperfusion of the brain parenchyma surrounding the AVM. Approximately 15% of AVMs are asymptomatic. Several risk factors exist, the most significant being the presence of intranidal or perinidal aneurysms (42). The estimated annual risk of rebleeding within the first five years is 6–25% (42). Consequently, treatment for previously ruptured AVMs is always indicated. Management is multimodal, including stereotactic radiosurgery, microsurgery, endovascular treatment, and their combinations (43,44). The ultimate goal is to completely exclude the AVM from the circulation, as shown in the example of a female patient from our database (Center of Radiology, University Clinical Center of Serbia) in **Figure 2**. If conservative management is indicated, the AVM is monitored annually via MRI and MRA to assess for arterial or venous aneurysms and signs of inflammation, such as new perinidal hyperintensities on FLAIR sequences (44).

b) Dural arteriovenous fistulas (dAVFs) are acquired anomalies. The most commonly affected age group consists of individuals between 20 and 40 years of age (45). The two most common classifications according to Cognard and Borden (listed in **Table 1**) are based on the route of venous drainage (dural sinus or cortical vein), the direction of blood flow within the venous sinus (antegrade or retrograde), and the presence of venous ectasia (45). The risk of hemorrhage is associated with the type of venous drainage. The primary therapeutic option is endovascular treatment (46). Conservative management is reserved for low-grade dAVFs where the sole symptom is tinnitus (ringing in the ears).

Table 1. The Spetzler-Martin classification for AVMs downloaded from Mladenovic A.S., Markovic ZZ, Hyodoh H. Anatomic differences of the distal aorta with dilatation or aneurysm between patients from Asia and Europe as seen on CT imaging, European Journal of Radiology, 2012; 81(9): 1990-7.

Diameter of the nidus	Small (<3 cm)	1 point
	Medium (3–6 cm)	2 points
	Large (>6 cm)	3 points
Eloquence of the adjacent brain	Non-eloquent	0 point
	Eloquenta	1 point
Venous drainage	Superficial cerebral venous system only	0 point
	Involvement of the deep cerebral venous system	1 point

Sometimes, large DAVFs can cause seizures and acute or chronic encephalopathy syndromes due to venous congestion. The risk of hemorrhage is not increased in low-grade DAVFs (Cognard I and IIa), whereas in high-grade DAVFs (Cognard IIb-IV) it can be up to 20% per year (47,48). A key distinguishing characteristic of DAVF, as opposed to AVMs, is the lack of an intra-axial nidus. A crucial diagnostic indicator of DAVFs is the presence of arterialized blood flow within the venous system (either in the venous sinuses or cortical veins), as observed on TOF angiography (48). A special type of DAVF is carotid-cavernous fistulas (CCFs), which present abnormal shunts between the branches of the internal and/or external carotid artery and the cavernous sinus. Most of these fistulas can be treated safely and effectively by endovascular embolization (49).

c) Capillary telangiectasias are typically asymptomatic, acquired anomalies characterized by a cluster of dilated capillaries interspersed with normal brain parenchyma (50). Due to their slow hemodynamic flow and the small caliber of the vessels, most lesions are occult on conventional angiographic imaging with a negligible risk of hemorrhage (50). On MRI, they exhibit a characteristic "brush-like" or "patchy" enhancement pattern on post-contrast images, with associated hypointensities on SWI sequences (51,52). The management of brain capillary telangiectasias is predominantly conservative.

d) Cavernous malformations (cavernomas) represent cerebral vascular malformations without an AV shunt. They are of genetic etiology, typically asymptomatic, and carry a low risk of hemorrhage (52). Due to their slow blood flow, they are occult on angiographic sequences; therefore, endovascular treatment is not an option. By nature, they are benign formations composed of multiple small, blood-filled cavities lined by endothelium, containing no intervening brain parenchyma (52). These vascular malformations can cause headaches and seizures (with a frequency of up to 25%) (53). On MRI, cavernomas exhibit a characteristic morphological appearance: a "popcorn" configuration on T2W, with mixed signal intensity, and a peripheral hypointense ring corresponding to hemosiderin deposits (53,54). If aggressive treatment is indicated, options include microsurgery or stereotactic radiosurgery (53).

e) Developmental venous anomalies (DVAs), also referred to as venous angiomas, represent the most prevalent congenital vascular malformations (54). Mostly asymptomatic, occasionally may cause headaches, seizures, hemorrhage, or focal neurological deficits. They present a characteristic MRI finding, specifically on post-contrast T1W and SWI sequences, in the form of a "palm tree" or "caput medusae" configuration (54). Because these malformations drain functional brain tissue, no surgical or endovascular treatment is indicated, as obliteration would lead to venous infarction of the brain tissue. Conservative management is reserved for rare symptomatic cases (e.g., antiepileptic therapy) (55).

f) Spinal vascular anomalies can develop in any part of the spine and include spinal dural fistula (SDAVF), arteriovenous malformation (AVM), and spinal arteriovenous fistula (SAVF). SDAVFs are acquired and characterized as low-flow shunts, typically located within the dural sleeve of the dorsal nerve root, most commonly in the thoracic region. Dural AV fistulas (Type I) account for the majority of spinal AV shunts (56). The typical clinical scenario involves a middle-aged or elderly male with slowly progressive asymmetric sensorimotor symptoms, often treated for years as neuropathy, followed by a recent exacerbation of symptoms and the development of bowel, bladder, and sexual dysfunction (57). Once the diagnosis is confirmed, treatment is indicated.

Spinal arteriovenous malformation are congenital (Type III) lesions. Symptoms may be acute due to hemorrhage or slowly progressive as a result of congestive myelopathy and vascular "steal syndrome." (57). Management involves endovascular and microsurgical approaches, sometimes in combination with stereotactic radiosurgery. Spinal arteriovenous fistula is a congenital or acquired lesion (Type IV). They represent a direct, high-flow communication between a spinal artery (such as the anterior spinal artery) and a draining vein (58). Dilated venous vessels and large venous ectasias are typically present. These lesions are prone to rupture; however, if rupture does not occur, symptoms result from vascular steal syndrome. Endovascular intervention is the first-line treatment, with microsurgery reserved for cases where endovascular attempts are unsuccessful (58).

In summary, significant advancements in endovascular treatment (EVT) for central nervous system pathologies have been achieved over the past few decades. Randomized controlled trials regarding intracranial aneurysms have demonstrated a significant reduction in mortality and disability rates compared to microsurgical interventions, establishing EVT as the primary therapeutic modality (57,58).

CONCLUSION

Computed tomography and magnetic resonance imaging are essential for early diagnosis of vascular malformations, therapeutic planning, and risk assessment across surgical, endovascular, and radiological interventions. The utilization of these imaging technologies facilitates a deeper understanding of the etiology and the specific requirements for the therapeutic management of various vascular diseases, preoperative planning, and follow-up. Furthermore, MRI is critical for assessing the reduction of the nidus size, the extent of post-therapeutic edema, and the presence of radiation necrosis within the treatment field. While surgery remains the primary definitive treatment, embolization of AVMs and aneurysms remains a vital component of a multimodal approach to reduce the volume of the arteriovenous malformation before surgical resection or radiotherapy.

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IMIDŽING VASKULARNIH ANOMALIJA AORTE I KRVNIH SUDOVA VRATA I GLAVE

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Sažetak

Cilj preglednog članka je da prikaže najčešće vaskularne anomalije krvnih sudova glave i vrata, kroz detaljan prikaz njihovih kliničkih manifestacija, dijagnostičkih karakteristika na savremenim imidžing modalitetima, kao i odabir adekvatnog terapijskog pristupa. Vaskularne malformacije nastaju kao rezultat greške u razvoju krvnih i limfatičnih sudova formirajući abnormalne vaskularne strukture prisutne na rođenju. Obično rastu proporcionalno sa rastom deteta, mada postoje periodi ubrzanog rasta i širenja. Bez lečenja, vaskularne malformacije ne regrediraju. Mogu se klasifikovati prema hemodinamskim karakteristikama u dve grupe: na sporoprotočne anomalije (u koje spadaju kapilarne malformacije, limfatične malformacije i venske malformacije) i na brzoprotočne anomalije (u koje spadaju arteriovenske malformacije i arterijske malformacije). Incidenca AVM je u porastu; većina je klinički asimptomatska, dok je 12% pacijenata sa simptomima bolesti. U slučaju krvarenja, stopa mortaliteta je 10-15% sa morbiditetom u rasponu od 30 do 50%. Ne postoji polna predilekcija. Kompjuterizovana tomografska angiografija (CTA) i magnetno rezonantni imidžing (MRI) omogućavaju adekvatan izbor najboljeg terapijskog pristupa (operativnog ili interventnog) i rešavanje mogućih uzroka morbiditeta i mortaliteta uz procenu rizika od primene hirurškog, endovaskularnog ili radiološkog pristupa. Primenom savremenih imidžing tehnika moguće je vizualizovati komplikacije kao na primer hemoragiju, moždani edem i atrofiju mozga. Glavni vid terapije je i dalje hirurški, ali embolizacija zauzima značajno mesto poslednjih godina. Savremene tehnike snimanja i razvoj novih stentova i embolizacionih materijala pružaju mogućnost poboljšanja kvaliteta života pacijenata sa vaskularnim malformacijama.

Ključne reči: arterijsko-venske malformacije, magnetno rezonantni imidžing, kompjuterizovana tomografska angiografija, aneurizme, venske displazije.

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