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Imaging of Carotid Dissection

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Abstract

Purpose of Review Here, we describe the four primary imaging modalities for identification of carotid artery dissection, advantages, limitations, and clinical considerations. In addition, imaging characteristics of carotid dissection associated with each modality will be described.

Recent Findings Recent advances in etiopathogenesis describe the genetic factors implicated in cervical artery dissection. MRI/MRA (magnetic resonance angiography) with fat suppression is regarded as the best initial screening test to detect dissection. Advances in magnetic resonance imaging for the diagnosis of dissection include the use of susceptibility-weighted imaging (SWI) for the detection of intramural hematoma and multisection motion-sensitized driven equilibrium (MSDE), which causes phase dispersion of blood spin using a magnetic field to suppress blood flow signal and obtain 3D T1- or T2*-weighted images. Digital subtraction angiography (DSA) remains the gold standard for identifying and characterizing carotid artery dissections.

Summary Carotid artery dissection is the result of a tear in the intimal layer of the carotid artery. This leads to a "double lumen" sign comprised of the true vessel lumen and the false lumen created by the tear. The most common presentation of carotid artery dissection is cranial and/or cervical pain ipsilateral to the dissection. However, severe neurological sequelae such as embolic ischemic stroke, intracranial hemorrhage, and subarachnoid hemorrhage can also result from carotid artery dissection. Carotid artery dissection can be identified by a variety of different imaging modalities including computed tomographic angiography (CTA), MRI, carotid duplex imaging (CDI), and digital subtraction angiography (DSA).

Keywords Carotid artery · Craniocervical dissection · Computed tomographic angiography · Magnetic resonance imaging · Magnetic resonance angiography · Digital subtraction angiography · Carotid Duplex · Ultrasonography

Abbreviations

CeAD	Cervical artery dissection
CD	Carotid Duplex
CDI	Carotid Duplex imaging
CT	Computed tomography
CTA	Computed tomographic angiography
CTP	CT perfusion
DSA	Digital subtraction angiography
FLAIR	Fluid attenuation inversion recovery
GFR	Glomerular filtration rate
MR	Magnetic resonance
MRA	Magnetic resonance angiography
MRI	Magnetic resonance imaging
SWI	Susceptibility-weighted imaging
TOF	Time of flight

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Introduction

Dissections arise secondary to a tear in the intimal layer of a vessel. Blood then enters the false or pseudolumen of the vessel wall and forms an intramural hematoma. Some dissections, however, are caused by a primary intramural hematoma [1]. Carotid and vertebral artery dissections have a close association with headache and craniofacial pain. Headache is the most frequent presenting symptom of carotid dissection, occurring in 60% to 95% of patients [2]. While pain can be slow and gradual in onset, about 20% present with an acute onset of severe pain ipsilateral to the dissected artery consistent with a thunderclap headache. About 25% of patients can have neck pain [3]. It is important to note that pain and mechanical triggers may be absent in patients aged ≥ 60 years presenting with dissection [4•]. A history of migraine has been associated with an increased risk for cervical artery dissection [5, 6•, 7]. Carotid dissection should be considered particularly in young adults presenting with an acute stroke. Occlusive cervical artery dissection (CeAD), multiple CeAD, and vertebral dissection are associated with risk for delayed stroke [8•].

Dissections are classified on the basis of pathogenesis and location. Traumatic dissections are due to blunt trauma or rapid movements of the head in relation to the neck [9]. Spontaneous (non-traumatic) cervical dissections have an annual incidence of about 2.6–3.0 per 100,000 people per year; extracranial carotid and vertebral segments are more prone to dissection than intracranial segments [1, 10, 11]. Intracranial artery dissections more commonly affect the posterior circulation when compared to the anterior circulation. The most common clinical manifestations of intracranial dissections are headache (80%), subarachnoid hemorrhage, and ischemia [12•]. No predisposition based on sex has been reported. Genetic imbalance and copy number variants affecting cardiovascular system development may contribute to the risk of CeAD, while variation in PHACTR1 allele is associated with a lower risk [13•, 14•]. Higher rates of university education are observed in patients with CeAD compared with non-CeAD [15]. Connective tissue disorders, family history, and smoking are some predisposing factors for spontaneous dissections. Carotid endarterectomy and digital subtraction angiography (DSA) are examples of iatrogenic causes for dissection.

Early identification of dissection and its treatment is integral for prevention of neurological sequelae, particularly recurrent stroke and disability. In this article, we focus on the imaging modalities used for the identification of craniocervical carotid dissection. A suggested algorithm for neuroimaging of craniocervical dissection is shown in Fig. 1.

CTA

This technique involves intravenous injection of iodinated contrast agent, typically 70–100 mL of Omnipaque-350 is injected at 3.5–4.5 mL/s, and helical CT scans are obtained from the aortic arch to the vertex. Sagittal, coronal, and 3D reconstructions are produced from axial images. These computed tomographic angiography (CTA) images have one half the spatial resolution of DSA and twice that of magnetic resonance angiography (MRA) [16]. The speed of image acquisition and widespread availability in most hospital settings make CTA the diagnostic modality of choice in clinical scenarios where dissection is suspected. Both extracranial and intracranial circulations can be evaluated in less than 10 s with the same injection of contrast media. The speed of acquisition is of particular importance in the setting of trauma, as it allows for the imaging of clinically unstable patients without compromising patient monitoring. Axial source images along with their 3D reconstructions allow for identification of arterial dissection and intimal tears and accompanying medial or subendothelial hematoma. The most common finding in dissection is an irregular and asymmetrical vessel, followed by identification of an intramural hematoma which appears as a crescentic hyperdensity with thickening of the vessel wall without a change in vessel caliber [17•]. CTA can also detect intimal flaps and dissecting aneurysms (false or pseudoaneurysm), which are a common consequence of extracranial dissection, seen in 13–49% of patients with CeAD

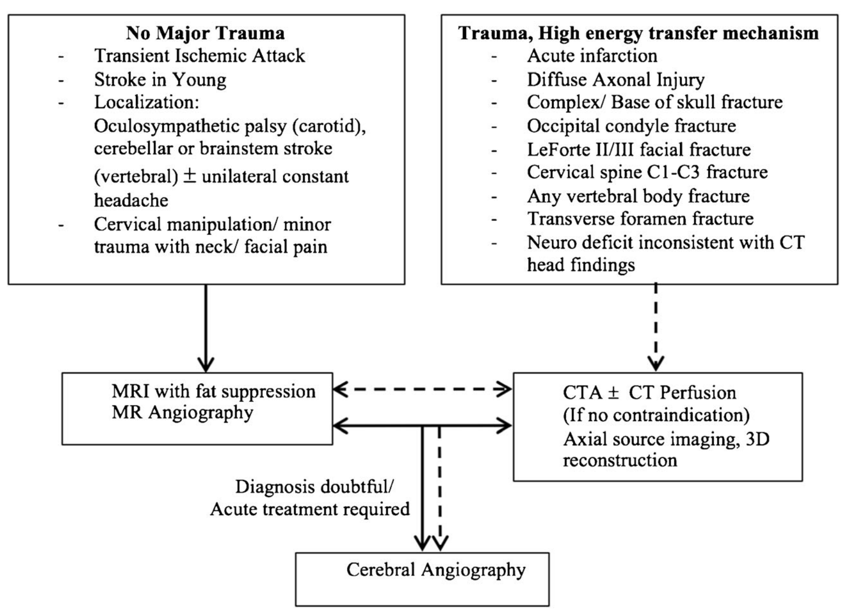

Fig. 1 Algorithm for diagnostic evaluation of craniocervical dissection

followed by a benign course [18•]. Flame-shaped pseudo-occlusion of the cervical internal carotid artery can mimic carotid dissection on CTA [19]. Studies comparing imaging modalities for the diagnosis of vertebral dissections versus internal carotid dissections have reported that CTA may be preferential for vertebral dissections given the smaller vessel diameter and close proximity to bony structures in the neck [20, 21]. CT perfusion (CTP) imaging is increasingly used in tandem with CTA, particularly in patients presenting with acute neurological deficits and a high National Institute of Health Stroke Scale. CTP can yield information on the resultant distal intracranial hemodynamics in the setting of acute dissection and can aid in patient selection for mechanical endovascular reperfusion for patients with acute ischemic stroke with an ischemic penumbra.

The sensitivity (64–100%), specificity (67–100%), positive predictive value (65–100%), and negative predictive value (70–100%) of CTA for the detection of cervico-cephalic arterial dissection compares favorably with DSA [22–24]. CTA is superior to MRA for the diagnosis of pseudoaneurysms, intimal flaps, and high-grade stenosis [24]. CTA is dependent on accurate timing of contrast bolus which can be compromised by poor vascular access, reduced cardiac ejection fraction, and valvular heart disease. Streak artifacts from implants and beam-hardening artifact at the skull base can affect source and reformatted images [25]. While relatively safe, well-tolerated, and less-invasive compared to DSA, CTA does involve exposure to radiation and iodinated contrast which can be an issue in patients with allergies to contrast material and renal dysfunction. CTA is also relatively contraindicated in children and during pregnancy.

MRI and MRA

The combination of MRA with axial T1-weighted MRI cervical imaging with fat suppression allows for non-invasive imaging of dissection, and allows for better identification of small intramural hematomas [1]. MR evaluation of dissection utilizes multiple sequences including conventional T1-, T2-weighed, and fluid attenuation inversion recovery (FLAIR) axial MRI imaging, and MRA performed with 2Dl time of flight (TOF), 3Dl TOF, or phase contrast techniques. This allows for simultaneous imaging of the brain and the major cervical and intracranial arteries. Non-contrast MRI is especially beneficial for patients with renal dysfunction or iodinated IV contrast allergy.

MR angiography can be performed using 2D TOF, 3D TOF, and phase-contrast. TOF MRA derives contrast between flowing blood and the stationary tissues by altering the magnetization of tissues in the field of view, such that the magnitude of signal from flowing blood is large. The extent of tissue exposure to excitation pulse is directly proportional to a greater saturation of its protons, and a weaker signal. Using thin slices and few excitation pulses, signal from flowing blood remains strong even in a large field of view [26•]. 2D TOF can image longer arterial segments in a short time, however, is subject to flow-related signal artifacts. 3D TOF techniques using multiple overlapping thin-slab angiography (MOTSA) use thin overlapping slabs of slices (as opposed to contiguous ones in older 2D techniques), which results in a decrease in the number of excitation pulses in one slice, thereby yielding a better signal to noise ratio. The use of gadolinium based dyes in contrast-enhanced MRA yields higher quality images. The least frequently performed method of MRA is the phase contrast (PC) technique, where contrast between flowing blood and stationary tissue is derived by manipulating the magnetization phase of tissues, such that the phase emanating from stationary tissues is zero, and flowing blood is different than zero [26•]. PC MRA can result in overestimation of flow rate, such as in patients with heart failure or significant vascular stenosis. This results in images with low intraluminal signal and low signal to noise ratio. Repeat scanning is thus required which increases procedure duration and the potential for motion producing artifacts [27].

The characteristic finding on MRI in extracranial carotid dissection includes a decrease or absence of signal flow void and a crescent sign resulting from narrowing of the vessel by intramural dissection of blood with the appearance of a semilunar spiraling peri-arterial rim of intramural hematoma on axial cross-sectional T1-weighted and FLAIR sequences [1, 28–31]. The hyperintense signal in a dissected vessel corresponds to intramural hematoma with methemoglobin signal intensity. The age of the dissection can be determined based on the signal intensity of the hematoma on T1- and T2-weighted MR imaging. During the hyperacute phase (first few hours) and acute phase (first 48 h), the intramural hematoma consists primarily of oxyhemoglobin and deoxyhemoglobin, respectively, and appear isointense on T1 relative to surrounding tissues and thus can be hard to detect [32]. Subacute hematoma (after 48–72 h) contains intracellular and extracellular methemoglobin and appear hyperintense on both T1- and T2-weighted imaging [12•, 17•]. Proton density or T2-weighted images can be used to identify intimal flaps, which appears as a curvilinear, hypointense line that separates the true lumen from the hematoma on long TR sequences [17•]. High-resolution 3 Tesla imaging and three-dimensional acquisition of fat-suppressed sequences with black-blood effect uses double inversion-recovery technique to null blood signal, thereby providing excellent visualization of vessel lumen; this increases the sensitivity and specificity of the images, and can improve detection of an intramural hematoma [33, 34]. Recent studies have demonstrated the use of susceptibility-weighted imaging (SWI) for the detection of intramural hematoma [35]. A novel technique similar to diffusion-weighted imaging, termed multisection motion-sensitized driven equilibrium (MSDE), has been recently described with clinical utility in dissection imaging. MSDE causes phase dispersion of blood spin using a magnetic field to suppress blood flow signal, producing 3D T1- or T2*-weighted images [36]. By obtaining thin slices (0.8 mm), small intramural hematomas are delineated as hyperintense lesions even in small arteries; a good diagnostic performance has been described for the detection of intracranial vertebral dissection [36, 37•].

Other abnormalities that can be delineated on MR include enlargement of the vessel diameter, hyperintense signal from the entire vessel, compromise of the vessel lumen by adjoining tissue with abnormally increased signal, and poor to no visualization of the vessel [31]. MRI in tandem with MR angiography of the brain can diagnose acute ischemic infarctions secondary to dissection. The stroke pattern in carotid dissection is predominantly cortical (> 80%), followed by subcortical (60%), with middle cerebral artery territory most commonly affected (99%), followed by border zone infarcts (5%), anterior cerebral artery (4%), and posterior cerebral artery (3%) [38, 39].

In comparison to DSA, MR angiography has a reported sensitivity (50–100%), specificity (29–100%), positive predictive value (43–100%), and negative predictive value (89%) for the detection of cervico-cephalic arterial dissection [21]. This variability is largely attributed to age differences of the hematoma, inclusion of both carotid and vertebral dissections, and the use of fat-suppression imaging or a lack thereof. MRI/MRA has a lower sensitivity and specificity for detection of vertebral dissection when compared to carotid artery dissection [40]. However, a single center study that included 164 patients in a "MR first for dissection" concept found vertebral dissections in 73% patients, and cervical dissections in 27% [41•]. The American Heart Association (AHA), American Stroke Association (ASA), and the International Headache Society recommend MRI/MRA with fat suppression as the best initial screening test [42, 43]. Newer techniques such as bolus timing and time-resolved contrast-enhanced MRA were also not performed in several studies. 3Dl TOF MRA can miss dissecting aneurysms during the acute stage if the hematoma is isointense [30]. MRI is also less sensitive for the detection of intracranial dissections, and DSA is the standard in such cases. Use of gadolinium requires that the patient have a glomerular filtration rate (GFR) of greater than 30 mL/min to decrease the chance of nephrogenic systemic sclerosis, also termed nephrogenic systemic fibrosis [44].

Carotid Duplex Imaging

Carotid Duplex Imaging (CDI) is the least invasive imaging modality used to identify carotid dissection. CDI consists of Doppler imaging wherein the peak systolic velocity is utilized to grade stenosis and brightness-mode (B-mode) imaging which allows for plaque characterization. Additional information can be added to B-mode by adding color flow Doppler wherein the direction of flow can be visualized based on the assigned color scale. In addition, Power Mode Doppler allows identification of slow-flow states by representing non-direction dependent blood flow, thereby increasing the sensitivity of identifying slow-flow versus no-flow states. A complete study also includes characterization of the direction of flow within each vertebral artery as antegrade or retrograde. CDI is limited to evaluation of the cervical portion of the carotid artery and, as such, is less diagnostic in individuals with a short neck on those whose carotid bifurcation occurs above the angel of the jaw.

The main advantages of CDI are that it is inexpensive, safe, portable, and can be performed at the bedside in many clinical settings [45•]. In contrast, the three other diagnostic modalities can only be performed in the appropriate diagnostic suite using costly technology and highly specialized personnel with some element of time delay as compared to CDI. In the case of carotid artery dissections, CDI often demonstrates a "double lumen sign" on B-mode which consists of the true lumen of the vessel and the false lumen created by the dissection [17•]. In some cases, an intraluminal hematoma may be identified

Fig. 2 Digital subtraction angiography demonstrating dissection with a flame-shaped tapering of the vessel with resultant stenosis. Also demonstrated is a pseudolumen (arrow), created by the subadvential tear

characterized as echodense material within the lumen. Due to the mass effect of the false lumen, the Doppler spectra may demonstrate a high-resistance pattern initially characterized by delayed systolic acceleration with reduced diastolic flow which can progress to bidirectional systolic flow with minimal diastolic flow. Ultimately, the compression from the intraluminal thrombus contained in the false lumen may lead to a low velocity Doppler waveform [45•]. Furthermore, compensatory hyperemia through the vertebral arteries may be noted. When the sample volume is reduced and placed within the false lumen, the direction of flow within the false lumen may be antegrade, retrograde, or bidirectional. It is important to note that when a dissection is identified which can be traced back to the common carotid artery, it usually indicates the presence of an aortic dissection [46].

DSA

DSA remains the gold standard for identifying and characterizing carotid artery dissections. As the most invasive form of vascular imaging, the technique involves placing a femoral sheath introducer into a left common femoral artery followed by the introduction and advancement of a catheter into the carotid artery of interest under direct fluoroscopy. Contrast is then injected through the catheter, and images are obtained using time controlled x-rays. The images are subtracted from a pre-contrast image, hence the term digital subtraction angiography [47]. DSA allows for dynamic characterization of the blood flow across the lesion. However, these advantages come with additional risks of vascular perforation, stroke, retroperitoneal hemorrhage, and contrast-induced nephropathy which can be reduced in the hands of experienced operators at high-volume centers [48].

Most commonly, DSA demonstrates a flame-shaped tapering of the vessel with resultant stenosis. This results in the formation of a pseudolumen (the potential space created by the subadventitial tear) and a true lumen (Fig. 2).

A terminology and grading of imaging criteria for intracranial artery dissection have been proposed by Debette et al. (Table 1). DSA however, can miss a carotid dissection in the less common scenario wherein the dissection involves

Table 1 Proposed terminology and grading of imaging diagnostic criteria for intracranial artery dissection

Proposed terminology for imaging diagnostic criteria of intracranial artery dissection
At least one of the three following features should be present when diagnosing an intracranial artery dissection:
• Fusiform or irregular aneurysmal dilation at a non-branching site of an intracranial artery, with at least one of the following criteria:
− Intramural hematoma (hyperintense rim on images with T1-weighted MRI), intimal flap, or double lumen*
− Rapid change in morphology on repeated imaging (increase or reduction in size, subsequent appearance of stenosis)
− Association with a focal stenosis (so-called pearl-and-string sign)
• Long filiform or irregular stenosis of an intracranial artery, with at least one of the following criteria:
− Intramural hematoma (hyperintense rim on images with T1-weighted MRI), intimal flap, or double lumen*
− Rapid change in morphology on repeated imaging (increase or reduction in size, or subsequent appearance of aneurysmal dilation)
− Association with a fusiform or irregular aneurysmal dilation (so-called pearl-and-string sign)
• Occlusion of an intracranial artery that recanalizes in either a fusiform or irregular aneurysmal dilation at a non-branching site, or a long filiform or irregular stenosis
Proposed grading of imaging diagnostic criteria for evidence of intracranial artery dissection
• Definite intracranial artery dissection
− Stenosis or occlusion of an intracranial artery secondarily developing towards a fusiform or irregular aneurysmal dilation at a non-branching site
− Intramural hematoma, intimal flap, or double lumen
− Pathological confirmation of intracranial artery dissection
• Probable intracranial artery dissection
− Fusiform or irregular aneurysmal dilation and focal, long filiform, or irregular
− Stenosis (so-called pearl-and-string sign) without subarachnoid hemorrhage, or still present > 1 month after subarachnoid hemorrhage
− Fusiform or irregular aneurysmal dilation at non-branching site with rapid change in morphology (increase or reduction in size, or subsequent appearance of stenosis)
• Possible intracranial artery dissection
− Fusiform or irregular aneurysmal dilation at non-branching site without change in morphology on repeated imaging within 6–12 months after first imaging
− Long filiform or irregular stenosis of an intracranial artery, with reduction in size or disappearance over time

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*Double lumen should be carefully differentiated from fenestration (which is an anatomical variant) the subadvential layer of the vessel, as the modality only images the vessel lumen which may not be impacted early on in the course [17•].

Conclusion

Carotid artery dissection often presents with ipsilateral neck pain with or without cephalgia. It can be complicated by various neurologic sequelae including acute ischemic stroke, subarachnoid hemorrhage, etc. Diagnosis can be confirmed by various neuroimaging modalities including MRI, CTA, CDI, and DSA; each of which offers their own advantages and disadvantages based on the clinical scenario.

Acknowledgements Figure 2 courtesy of Dhruvil Pandya, MD

Compliance with Ethical Standard

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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