Radiologic Imaging of Carotid-Cavernous Fistulas (CCF)

Gilad Evrony, Harvard Medical School Year III
Gillian Lieberman, MD
Goals

• Understand the anatomy and physiology of CCF
• Recognize the diversity of clinical presentations of CCF
• Learn the radiologic tests available for CCF and imaging findings
Outline

• Patient presentation
• Relevant anatomy
• Differential diagnosis
• Radiologic imaging
• CCF pathophysiology
• Patient outcome
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Patient Presentation

- **64 year old man presenting with complete L eye vision loss.**

- **4 mo. prior:** Began having almost continuous L frontal pulsating headaches (HA), L eye “squeezing” pain, occasionally also R side. Also intermittent L ear pulsing “whooshing” sound matching pulse when supine.

- **2 mos. prior:** Complete left Bell’s palsy. Followed 1 day later by worsening of headache. MRI head nl. Discharged with 1wk prednisone + valacyclovir.

- **7 wks prior:** Bell’s palsy resolving, HA improved. Ophthalmology exam nl (VF, EOM, fundoscopy, tonometry).

- **6 wks prior:** Sudden onset diplopia (cars appear “double” while driving). Also occasional night sweats. Outside hospital finds partial R CN VI palsy, and almost resolved Bell’s palsy. NCHCT nl. One day later – worst HA to date. Emergent NCHCT, MRI, and MRA/MRV, but still no clear diagnosis. Started on prednisone. HA resolved to mild pain. Discharged with presumed Tolosa-Hunt syndrome.
Patient Presentation – cont’d

- **5 wks prior:** Ophthalmology follow-up- diplopia improved, but now some L CN VI deficit. Exam otherwise nl. Admitted to BIDMC for further workup. Workup and MRI unrevealing. Told to return if cranial neuropathy changes or reactivates.

- **1 wk prior:** Mild R CN VI deficit remains. L Bell’s completely resolved. Ophthalmology exam normal.

- **5 days prior:** Tapers steroids down to 10mg.

- **4 days prior:** Diplopia resolving, but notices it is because L eye gradually becoming blurry.

- **2 days prior:** Ophthalmology exam- decreased L eye visual acuity (20/80), upper L eye VF deficit, minimally reactive L pupil. Mild L CN VI palsy. Fundoscopy nl.

- **Day of admission:** Patient notes complete L eye vision loss. On admission found to have complete L eye vision loss, mild L CN VI palsy, normal fundoscopy. On later exams also: mild R CN VI palsy, L pupil constriction deficit (when shining light in R eye), L eye elevation deficit, L eye 1-2mm proptosis, auscultated bruit on upper left face.
Patient History

- **Labs:** All normal: blood cultures, CSF, ESR/CRP, coags, temporal artery biopsy, ANA, ANCA, ACE, Lyme, RPR, HSV, HIV, CSF TB, RF, SSA/SSB, IgG1-4.

- **Other imaging:** CXR – 5mm LLL nodule. CT chest – 5mm RML nodule, R apical/L lingula scarring.

- **PMH:** Latent TB, trachoma (childhood), chronically dry eyes, mild b/l cataracts, narrow angles s/p b/l iridotomies, MVA with whiplash (2007).

- **Meds:** isoniazid, pyridoxine, bactrim, prednisone

- **Social Hx:** Born and raised outside the US, moved to US 25 yrs ago. Retired, lives at home with his wife. No T/A/D.

- **Family Hx:** Non-contributory.
This is a lot of information!
So let’s summarize the key points…
Patient History – Key Points

• Four months of nearly continuous left-sided pulsating HA and pulsatile tinnitus.

• Multiple cranial nerve palsies:
  – Complete left eye vision loss - **L CN II**
  – Left pupil constriction and EOM deficits – **L CN III**
  – Waxing/waning bilateral eye abduction deficits – **L and R CN VI**
  – Left Bell’s palsy, now resolved – **L CN VII**

• Headaches tend to worsen at night when supine, and on two occasions worsened in conjunction with onset of CN palsy.

• Surprisingly, fundoscopy is normal– no retinal congestion or ischemia. No chemosis, normal IOP, minimal proptosis → **posterior (retrobulbar) optic neuropathy**
Outline

• Patient presentation

➤ Relevant anatomy

• Differential diagnosis

• Radiologic imaging

• CCF pathophysiology

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Anatomy - Skull

Chiasmatic groove
Optic canal
Superior orbital fissure
Carotid groove
Foramen rotundum
Foramen lacerum
Foramen Valsalva
Foramen ovale

Anterior clinoid process
Tuberculum sellae
Sella turcica
Posterior clinoid process
Clivus
Petrous bone
Internal acoustic meatus

Dutton (2011)
Anatomy – Sinuses (superior view)

Netter (2011)
Anatomy – Sinuses (supero-lateral view)

Anatomy – Sinuses - drainage

- The cerebral sinuses (aka dural venous sinuses) are formed between the two layers of dura, and are the main veins draining cerebral blood and CSF from the skull via the internal jugular vein.

- The direction of drainage is determined by pressure differences → simple plumbing!

- The normal predominant direction of flow through the sinuses is important to know:
  - Group of superior sinuses (superior and inferior sagittal, straight, occipital) → confluence of sinuses → transverse sinuses → sigmoid sinuses → internal jugular vein.
  - Inferior sinuses/veins (sphenoparietal sinus, ophthalmic veins) → cavernous sinuses (CS) → superior and inferior petrosal sinuses → sigmoid sinuses → internal jugular vein.
  - The cavernous sinuses communicate with each other and also with the pterygoid plexus and basilar plexus.
Because the dural sinuses are a low-pressure system, small abnormalities in pressure can change and reverse drainage patterns, causing problems.
The cavernous sinuses contain and are adjacent to many cranial nerves.
Anatomy – Cavernous Sinus

The cavernous sinuses contain and are adjacent to many cranial nerves.

Dutton (2011)
Note how in MRI the rapid arterial flow in the ICA causes a dark signal (“flow void”) even though it is a contrast study.
Anatomy - ICA

Note the 4 loops of the ICA, with the cavernous segment approximately between the 3rd and 4th loops. This is an easy way to track the anatomy on imaging studies, especially angiograms.
Anatomy – ICA (lateral in situ view)

Note again the 4 loops of the ICA (not illustrated as clearly here), with the cavernous segment approximately between the 3rd and 4th loops.
Anatomy – Carotid Cavernous Fistulas (CCF)

CCF is an abnormal communication between the carotid arterial system and the cavernous sinus.

- Classified into four types based on the communicating artery/arteries (Barrow classification):
  - Direct connection from cavernous ICA
  - Connection from meningeal branches of ICA
  - Connection from meningeal branches of ECA
  - Connection from meningeal branches of ICA and ECA

Anatomy – Carotid Cavernous Fistulas (CCF)

- Type A CCFs are more common (~75%), and are higher flow.
- Types B, C, and D CCFs are lower flow fistulas.

High Flow
(type A, aka “direct” fistulas)

Low Flow
(types B, C, and D, aka “indirect” fistulas)
Anatomy – Carotid Cavernous Fistulas (CCF)

- CCFs increase the pressure in the cavernous sinuses and communicating sinuses, leading to changes in flow direction/drainage and symptoms.
- Keep in mind cerebral sinus anatomy as we review our patient:
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Differential Diagnosis

Multiple cranial nerve palsies (cranial polyneuropathy)

- Neoplasia (30%): primary brain tumor (meningioma, glioma, pituitary adenoma, etc), metastasis, lymphoma, carcinomatous meningitis, multiple myeloma.
- Vascular (14%): ischemia (brainstem, midbrain, nerves), diabetic neuropathy, aneurysm, cavernous sinus thrombosis, CCF (0.6%).
- Trauma (12%): orbit, temporal, sphenoid fractures.
- Infection (10%): meningitis (TB, other bacteria, fungal), viral (EBV, zoster), syphillis, mastoiditis.
- Autoimmune: Sjogren’s syndrome, vasculitis (giant cell arteritis, Wegener’s, Sjogren’s), idopathic hypertrophic pachymeningitis, SLE, systemic sclerosis, MS (5%), GBS/Fisher syndrome (9%).
- Idiopathic: sarcoidosis, Tolosa-Hunt syndrome (6%), orbital pseudotumor, Paget’s.

➢ Cavernous sinus is the most frequent location (25%).

Posteriors (retrobulbar) optic neuropathy

- Nerve ischemia: hypotension, vasculitis, vascular disease (HTN, diabetes, etc), dissection, embolism
- Inflammation: optic neuritis (MS, postviral), SLE, Sjogren, sarcoidosis
- Infection (viral, TB, syphillis, Lyme)
- Other: compression (neoplasm, aneurysm, abscess), trauma, nutritional (B12, folate), genetic (Leber’s), radiation, 1 reported case of CCF (Hashimoto, et al).

Differential Diagnosis

Huge Differential!

Here’s what remained after taking into account history, labs, initial imaging:

- **Neoplasia**: lymphoma, carcinomatous meningitis
- **Vascular**: nerve trunk ischemia, aneurysm, CCF, cavernous sinus thrombosis
- **Infection**: TB still possible but unlikely given CSF studies.
- **Idiopathic**: sarcoidosis (though pertinent labs normal), Tolosa-Hunt syndrome.

- Other neoplasia, brain parenchyma ischemia, autoimmune causes, infections ruled out by labs and imaging.

**What about the pulsatile tinnitus? This is quite a specific symptom…**

Due either to accelerated blood flow → audible turbulence OR ↑ perception of normal flow sounds.

- Arterial (22%): stenosis, aneurysm, anatomic variants.
- Arteriovenous connection (21%): CCF, AVM, vascular tumors.
- Venous (27%): increased ICP, cerebral sinus thrombosis, anatomic variants (e.g. sinus diverticulae)
- Superior canal dehiscence (1%), other (7%), unknown (22%)

*Percentages from Hofmann (2013) based on review of 563 patients.*
Differential Diagnosis

Pulsatile tinnitus is a *specific* finding *strongly* suggesting involvement of vasculature.

Now with an understanding of the anatomy and differentials, let’s review our patient’s imaging.
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6 wks prior to this admission
Axial T1 C+, fat suppressed

**Findings:** Multiple hypointense soft tissue densities in cavernous sinus (possibly thrombi), CS width mildly enlarged (boundary not concave), normal ICA (cavernous, C4 segment) flow voids, and sphenoid cyst.
Findings: Normal-appearing vessels. ICA (C4 segment), MCA, ACA, basilar artery.
5 wks prior – Axial T1 C+, fat-suppressed

**Findings:** Compared to prior Axial T1 (right), slight reduction in hypointense soft tissue densities in cavernous sinus (resolving thrombi?), CS wall less distended. Sphenoid cyst seen again.
Findings: **Dilated superior ophthalmic veins** (right 3.9mm, left 3.5mm). Normal size is up to about 2.5mm. This is a sign of elevated CS pressure since the SOVs drain into the CS (recall the anatomy).
Interim Diagnosis

At this point after extensive workup, including 2 MRIs, MRA/MRV, 2 CTs, a clear diagnosis was not reached and the patient was given a diagnosis of exclusion, Tolosa-Hunt syndrome (idiopathic inflammation of the cavernous sinus), a prednisone taper, and told to return if anything changed.

In retrospect, knowing the diagnosis was CCF, the hypo-intense lesions in the cavernous sinus (CS) may represent thrombi, an early stage in the formation of his CCF. Indirect CCF (types B, C, D) pathogenesis is not well understood, but CS thrombosis causing increased venous pressure is thought to be one possible cause of CCF. Increased venous pressure due to thrombi in some vessels may cause small vessels that drain dural carotid artery branches to expand and form new collaterals shunting to the CS. Alternatively, the thrombi may be due to flow disturbance from an already existing CCF.

The dilated SOVs were also in retrospect suggestive of CCF.
Four weeks later → left eye vision loss
Findings: Normal. No evidence of acute bleed. Note cavernous sinus outline can be faintly seen on non-contrast CT, but non-contrast CT is otherwise not very helpful for evaluating the CS.
Axial T1 C- Scan

Findings: Normal ICA flow void with multiple abnormal flow voids in cavernous sinus. The abnormal flow voids indicate arterialized flow in the CS possibly due to a CCF. Sphenoid sinuses and pituitary.
Coronal T1 C-

Findings: Normal ICA flow void with multiple abnormal flow voids in cavernous sinus. Sphenoid sinus and pituitary.
Findings: Dilated superior ophthalmic veins (right 4.0mm, left 4.1mm), optic nerve, superior, inferior, lateral, and medial rectus muscles, in the orbit.
Findings: Dilated superior ophthalmic veins (L>R).
We have seen the key findings in our patient on MRI: 1) abnormal flow voids in the cavernous sinus, and 2) dilated superior ophthalmic veins. Both suggested a carotid cavernous fistula.

Cerebral angiography, the gold standard in diagnosing CCF, was performed next to confirm this diagnosis.
First, a quick intro on cerebral angiography.
Radiologic Imaging – Cerebral Angiography

A catheter is passed via the femoral artery, and the carotid arteries are injected with contrast. Cerebral angiography can be divided into three phases:

- **Arterial phase**
- **Parenchymal phase**
- **Venous sinus phase**

Left internal carotid artery injection (AP view) of different patient with LICA aneurysm, but no CCF

**Findings:** Left ICA, aneurysm, ACA distribution arteries, MCA distribution arteries. Venous sinuses: superior sagittal, confluence, transverse, sigmoid.
Now let’s watch the angiography movies.
Our patient - LICA (AP view)
Abbreviations: LICA/RICA- left/right internal carotid artery.
LECA/RECA- left/right external carotid artery.

Different patient with LICA aneurysm, but no CCF
Let’s walk together through some key findings in the angiography.
Radiologic Imaging – Cerebral Angiography

Our patient - LICA (AP view)
Arterial phase

Different patient with LICA aneurysm, but no CCF

Findings: Abnormal arterial phase filling of venous sinuses (bilateral cavernous, intercavernous, inferior petrosal) and pterygoid plexus, from multiple branches of cavernous segment of LICA.
This study was diagnostic of a CCF. Venous sinuses should not opacify during the arterial phase. Opacification during the arterial phase indicates early shunting from the arterial system to the venous sinus system, in other words, a fistula!

Now, let’s see the lateral view and angiography of the other carotid arteries.
Our patient - LICA (lateral view)

Different patient with LICA aneurysm (no CCF)
Our patient - LICA (lateral view)
Arterial phase

Findings: LICA with abnormal arterial phase filling of cavernous sinus and pterygoid plexus. Also, distended left orbital vasculature.
Findings: Early parenchymal phase filling of dilated left superior ophthalmic vein (slow retrograde drainage of CCF via SOV), LICA and the eye.
Findings: Significant supply of CCF from RICA, with arterial phase drainage to bilateral cavernous sinuses, inferior petrosal sinuses, and pterygoid plexi.
Findings: Early arterial phase filling of the cavernous sinuses bilaterally, with drainage primarily via the inferior petrosal sinuses to the jugular vein.
To summarize, our patient’s CCF is supplied by all four carotid arteries: left internal and external, and right internal and external carotid arteries. It is therefore a bilateral type D CCF.

CCF- Menu of Radiologic Tests

• **CT head and orbit**, w/ and w/o contrast- for suspicion of trauma, skull fracture, mass lesions, bleeding. Can identify proptosis, cavernous sinus border, extra-ocular muscle and orbital vein enlargement, but not sensitive.

• **MRI head and orbit**, T1 w/ and w/o contrast and T2- more sensitive than CT, also allows detection of inflammation, CS flow voids, SOV dilation.

• **MRA, CTA**- basic vascular anatomy, may lack sensitivity for CCF types B-D.

• **Transcranial and orbital duplex ultrasound**- CS and SOV flow measurements, and SOV dilation.

• **Cerebral angiography**- gold standard, intervention.
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CCF Pathophysiology

- **Pathogenesis:**
  - **Type A** (direct fistula from cavernous ICA, high flow, 75-80% of CCFs) – most often due to head trauma, sometimes with associated skull fracture. It can also be due to aneurysm rupture.
  - **Types B, C, D** (aka dural CCFs, indirect fistula from meningeal branches of ICA/ECA, low flow) – pathogenesis unclear. Possibly tearing of dural meningeal arteries from various causes +/- thrombosis, leading to collateral neovascularization and fistula formation.
  - Other causes:
    - **Abnormal arteries:** Ehlers-Danlos, pseudoxanthoma elasticum, fibromuscular dysplasia → affect arterial walls, leading to aneurysms, abnormal collateral formation, and fistulas.
    - **Hypercoagulability** e.g. PT mutations, pregnancy → thromboses of cavernous sinus or dural ICA branches, leading to abnormal collaterals and fistulas.
CCF – Clinical Findings

Spectrum of presentations: Depends on venous flow!

- Most common: headache, pulsatile tinnitus, chemosis, proptosis.
  - Often, conjunctival injection is the only symptom – treated mistakenly for conjunctivitis.
- Other findings: cranial bruit, eye symptoms (usually unilateral) of eye pain, increased IOP, blurry vision, vision loss, diplopia, ophthalmoplegia, and other cranial nerve deficits.
  - Our patient’s presentation of CN VII and retrobulbar CNII deficits are not typical: Facial nerve palsies in CCF are rare (Jensen, et al), and in fact, only one other case of retrobulbar optic neuropathy has ever been reported (Hashimoto, et al)! Remember that our patient had normal fundoscopy and IOP (albeit s/p iridotomy), and only mild proptosis. The absence of other eye findings, yet with complete vision loss is not typical. Possible mechanisms include mass effect from dilated vessels or shunting of blood away from vessels supplying the nerve (arterial steal).
- Also, bleeding: cerebral hemorrhage (from posterior drainage to cerebral veins), and mouth, ear, nose bleeding (anterior drainage).
- Symptoms may change as venous drainage pathways change and thrombose.
- Indirect CCFs (types B, C, D) usually have gradual onset relative to direct CCFs (type A) that are usually more acute.
Acute type A CCF

Chronic type A CCF

Indirect CCF with L CNVI deficit

Posterior-draining CCF (white eye) with L CNIII deficit

Indirect right CCF, proptosis on CT.
CCF Treatment

- Conservative (for mild indirect CCFs): carotid compression maneuvers to slow flow in the fistula to promote thrombosis.
- Endovascular: transarterial or transvenous embolization.
- Open surgery
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Patient Outcome

- Cranial nerve deficits persisted and mild increase in proptosis noted.
- Due to concern for progressing symptoms and potential for right eye vision loss, he underwent a CCF transvenous coil embolization, which was successful.

Our patient - RICA (AP view)
Post coil embolization

Findings: Multiple coils throughout the right and left cavernous sinuses. Continued presence of type D CCF, with reduced flow in both cavernous sinuses and reduced supply from right carotid. Not shown: continued supply of CCF from left carotid with increased drainage via SOV.

- CT torso performed to rule out malignancy (which showed normal results), steroids discontinued, and discharged with close follow-up and instructions to return emergently if any new CN deficits.
Patient Outcome

• Follow-up 3 weeks later:
  – Clinically stable, with some improvement in pulsatile headache, though still present behind L eye, usually at night after sleeping for 3-4 hours.
  – Ophthalmology exam: Right eye- normal. Left eye- complete vision loss, mild elevation/depression deficit, abduction deficit, mild conjunctival injection and lid edema, pallor of optic disc, and marked thinning of inner retinal layers.
  – MRI/MRA/MRV: Unchanged dilated SOV and prominent cavernous sinuses bilaterally. Otherwise normal.

• Follow-up cerebral angiogram 7 weeks later:
  – Performed to make sure CCF flow is not redirecting to cerebral veins (risk of stroke). Angiogram showed improvement, with normal internal and external carotid arteries, and no significant residual cavernous sinus or SOV flow in the arterial phase (i.e. further thrombosis of fistula due to coil embolization).

• Open questions: Mechanism of CNII damage? Was Bell’s palsy due to CCF or unrelated? Was it chance that cranial nerve deficits tended to present after taper of steroids? What was the inciting event of the CCF?
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References