Internal Carotid Artery Stenosis: Imaging the Shrinking Lumen

Gregory Parker, Harvard Medical School Year III
Gillian Lieberman, MD

Learning Objectives

- Learn the menu of tests available to assess for carotid artery stenosis
- Review the arterial anatomy of the aortic arch and neck
- Learn to recognize carotid artery stenosis on different imaging modalities
- Learn a framework for thinking about etiologies of ischemic neurologic symptoms
- Understand how radiologic assessment of carotid artery stenosis impacts patient management

Our Patient

- Patient AB is a 65 y/o woman with a history of smoking, HTN, HLD, DM, and known bilateral carotid stenosis who presented with transient episodes of left-sided numbness and weakness.
- Episodes lasted as long as 30 seconds and then resolved with a return to baseline functioning.
- She was evaluated by MRI and found to have multifocal infarcts in the right middle cerebral artery territory indicative of embolic stroke.

TIA/Ischemic Stroke: Etiologies

- Large vessel atherothrombotic disease
  - Internal carotid artery (ICA) or vertebral artery atherothrombotic disease
  - Intracranial atherothrombotic disease
- Distant emboli
- Small vessel occlusive disease
- Systemic hypoperfusion

Caplan 2015

Transient Ischemic Attack: Imaging Evaluation

- Brain Imaging = "Identifying Damage"
  - MRI preferred, CT second line
- Neurovascular Imaging = "Identifying the Cause"
  - Carotid Doppler Ultrasound (CDUS), aka Duplex Ultrasound
  - MR Angiography (MRA)
  - CT Angiography (CTA)
  - Cerebral Angiography

Furie 2015

TIA: ACR Appropriateness Criteria

Variant 2: **Carotid territory or vertebrobasilar TIA, initial screening survey. (In these tables a TIA is the report of an historical transient ischemic event by the patient or other witness. The acute neurological deficit in progress must be treated as an acute stroke and can only be considered a TIA in retrospect if it resolves without intervention.)**

Radiologic Procedure	Rating	Comments	RRL*
MRI head without contrast	8		O
MRI head without and with contrast	8	See statement regarding contrast in text under "Anticipated Exceptions."	O
MRA head and neck without contrast	8		O
MRA head and neck without and with contrast	8	See statement regarding contrast in text under "Anticipated Exceptions."	O
CT head without contrast	8		☢☢☢
CT head with contrast	8		☢☢☢
CTA head and neck with contrast	8	Combined vascular and cerebral evaluation should be considered. MRI with DWI preferred if treatment not unreasonably delayed. See the Relative Radiation Level Information section for important radiation dose warning with multiple or repeated CT procedures.	☢☢☢
CT head perfusion with contrast	6	If directly employed in decision making and planning treatment. Appropriate if stenosis or occlusion found. Consider acetazolamide challenge to assess CVR if >24 hours since TIA. See the Relative Radiation Level Information section for important radiation dose warning with multiple or repeated CT procedures.	☢☢☢
US duplex Doppler carotid	6		O

Imaging tests ordered for our patient.

American College of Radiology 2011

Before we look at our patient's imaging, let us learn some basics about the carotid doppler ultrasound (CDUS)…

CDUS Ultrasound Basics

- Also known as “duplex ultrasound” because it incorporates two elements
  - Grayscale ultrasound = production of the anatomical ultrasound image
  - Spectral Doppler = calculates blood flow velocity

- Spectral Doppler primer
  - Transducer emits a signal with a specific frequency to a specified depth
  - The emitted signal interacts with moving blood and undergoes a frequency shift
  - The transducer detects the reflected signal frequency and calculates velocity of the blood flow based on the difference from the original signal frequency
  - Blood velocity helps determine the size of vessel lumen because as the lumen narrows the blood must flow faster

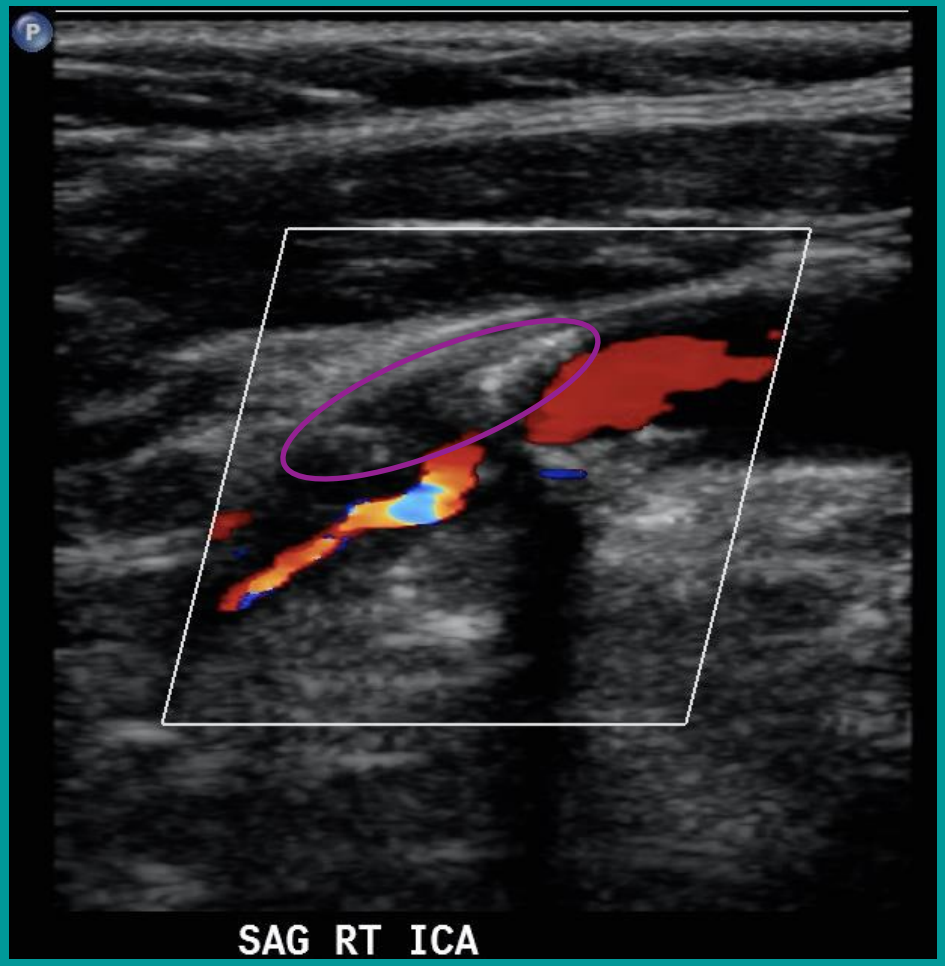
ICA Stenosis: Quantifying with CDUS

- Society of Radiologists in Ultrasound Consensus
  - <u>≤50% stenosis:</u> Peak Systolic Velocity (PSV)<125 cm/s AND observable plaque/intimal thickening
  - <u>50-69% stenosis:</u> PSV is 125-230 cm/s AND observable plaque
  - <u>≥70% stenosis:</u> PSV>230 cm/s AND observable plaque and luminal narrowing
  - Additional criteria include end-diastolic velocity and the ratio of ICA velocity to common carotid velocity

Grant 2003

Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Our Patient: CDUS Showing Stenosis



PACS, BIDMC **CDUS with Color Flow**

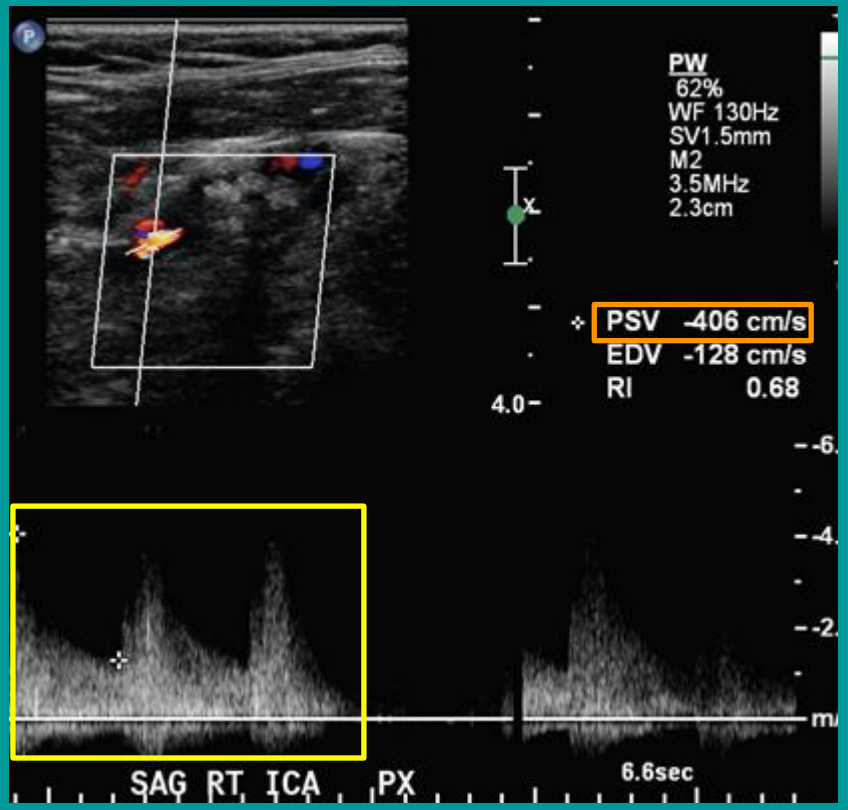
Right ICA showing plaque of heterogenous echogenicity and luminal narrowing.

Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Our Patient: Increased PSV on CDUS

PACS, BIDMC **CDUS Spectral Doppler**

Proximal right ICA showing PSV of 47.9 cm/s.



PACS, BIDMC **CDUS Spectral Doppler**

Stenosed right ICA with PSV of 406 cm/s, suggesting 70-99% stenosis, and a high resistance waveform.

ICA Stenosis: Risk Factors

- Similar to coronary atherosclerotic plaque genesis
  - Hypertension
  - Diabetes
  - Smoking
  - Dyslipidemia
  - Flow characteristics
    - Altered flow at the carotid bifurcation
    - Low shear stress at the carotid bifurcation
      - Associated with increased intima-media thickening

Gnasso 1996

Now that we have seen ICA stenosis on ultrasound let us compare CDUS to other imaging tests…

ICA Stenosis: Menu of Tests

Test	Sensitivity	Specificity	Main Pros/Cons
Duplex Ultrasound	89%*	84%*	Pro: inexpensive Cons: operator dependent, less anatomical information
CTA	76%*	94%*	Pro: image entire artery Cons: expensive, contrast required
Contrast Enhanced MRA	94%*	93%*	Pro: image of entire artery Con: expensive

Sensitivity and specificity are for detection of severe stenosis (>70%) compared to conventional angiography.

**Wardlaw 2006*

Since test characteristics alone do not suggest a clear winner among the imaging modalities, how should we choose a first line imaging test?...

ICA Stenosis: Choosing a Test

- Depends on the clinical context and the expertise of the individual institution*
  - Possible emergent surgical intervention → CTA*
  - Non-emergent → CDUS to evaluate degree of stenosis +/- MRA to confirm and provide comprehensive anatomic information*
- Some centers use only CDUS for pre-surgical evaluation‡

* *Jaff 2008*
‡ *Furie 2015*

Carotid Bruit: ACR Appropriateness Criteria

Clinical Condition: **Cerebrovascular Disease**

Variant 1: **Asymptomatic. Structural lesion on physical examination (cervical bruit) and/or risk factors.**

Radiologic Procedure	Rating	Comments	RRL*
US duplex Doppler carotid	8	May need to confirm with second noninvasive study.	O
MRA neck without contrast	8		O
MRA neck without and with contrast	8	See statement regarding contrast in text under "Anticipated Exceptions."	O
CTA neck with contrast	8	Multidetector CTA has higher spatial resolution than MRA with no flow artifact and better visualization of plaque calcium. May show late-filling "string" sign of severe ICA stenosis better than MRA. (Axial source images and reformatted maximum-intensity-projection [MIP] images preferred; 3D surface reformations may create misleading artifacts.) See the Relative Radiation Level Information section for important radiation dose warning with multiple or repeated CT procedures.	☢☢☢

Equivalent ACR appropriateness ratings for the non-invasive neurovascular tests highlights the need to use clinical context to choose an imaging modality.

American College of Radiology 2011

Now that we have learned about the imaging tests available let us look at some companion patient images…

Companion Patient #1

- This is a 67 year old woman with a history of hypertension and known bilateral carotid artery stenosis s/p left carotid endarterectomy presenting with one episode of transient right monocular vision loss lasting 40 seconds.
- She was evaluated with CTA in the emergency room.

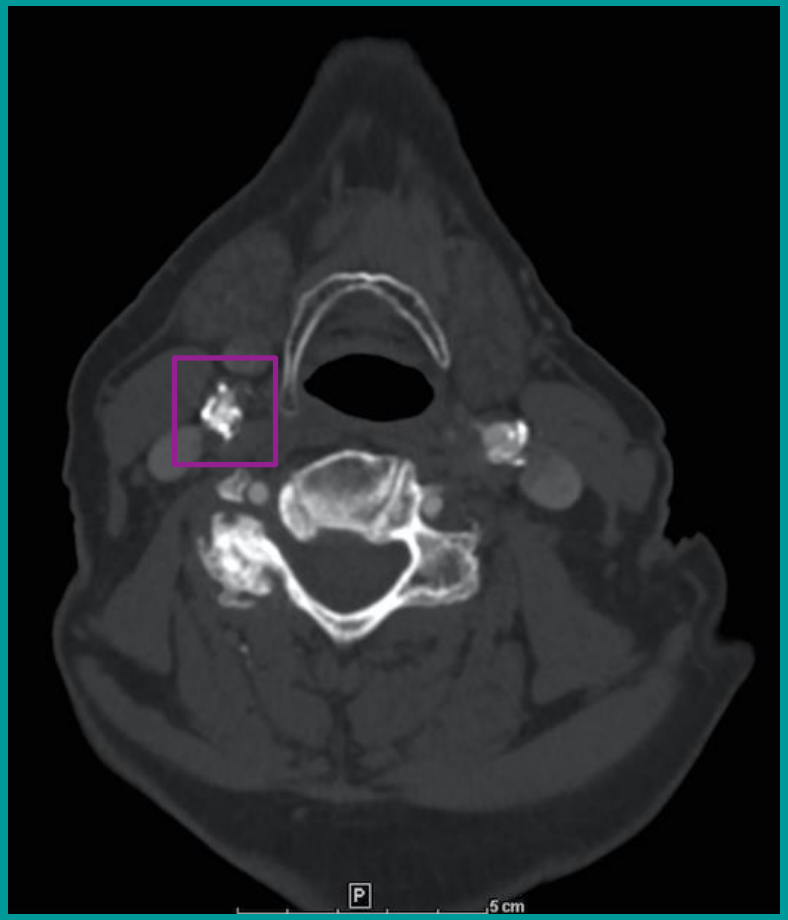
ICA Stenosis: Quantification on CTA or MRA

- North American Symptomatic Carotid Endarterectomy Trial (NASCET)
  - Percent ICA Stenosis = (1 - N/D)*100
  - N = diameter of the ICA lumen at the most stenotic portion
  - D = diameter of the ICA lumen at a point distal to the stenosis

North American Symptomatic Carotid Endarterectomy Trial Collaborators 1991

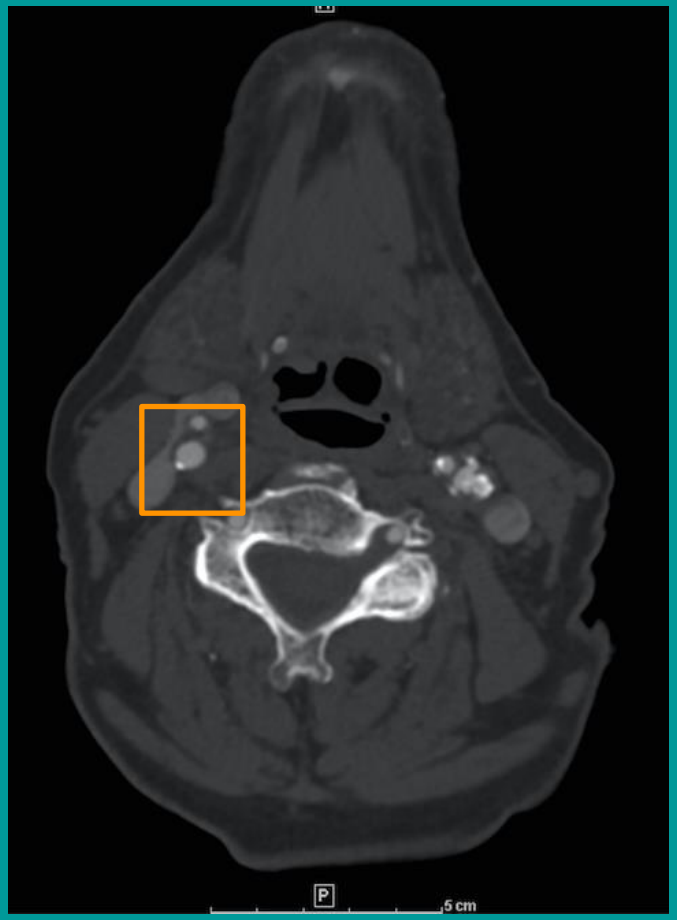
Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Companion Patient #1: CTA



PACS, BIDMC **C+ CT Angiogram**

ICA showing calcified atherosclerotic plaque and greater than 80% stenosis.

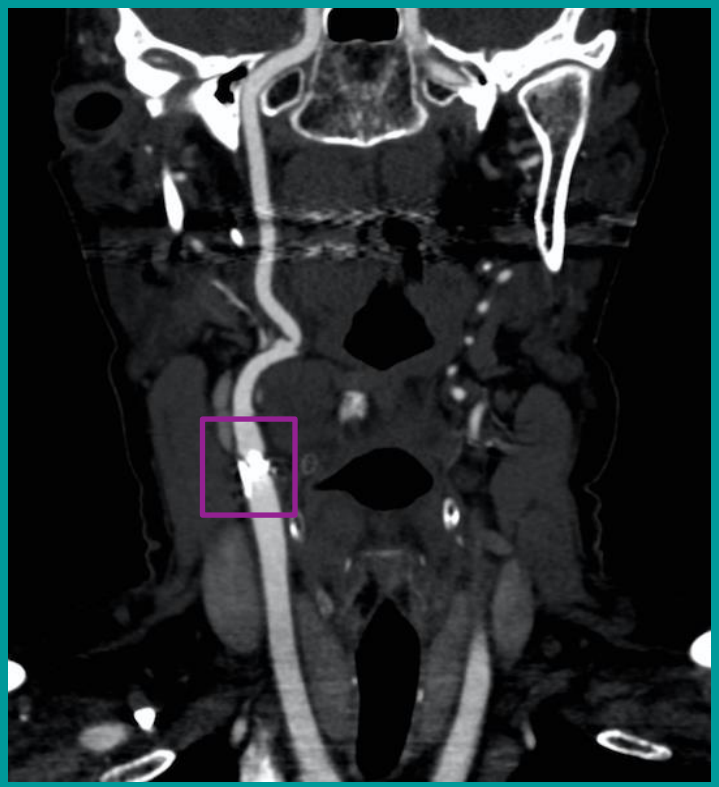


PACS, BIDMC **C+ CT Angiogram**

ICA distal to the stenosis showing a widely patent lumen.

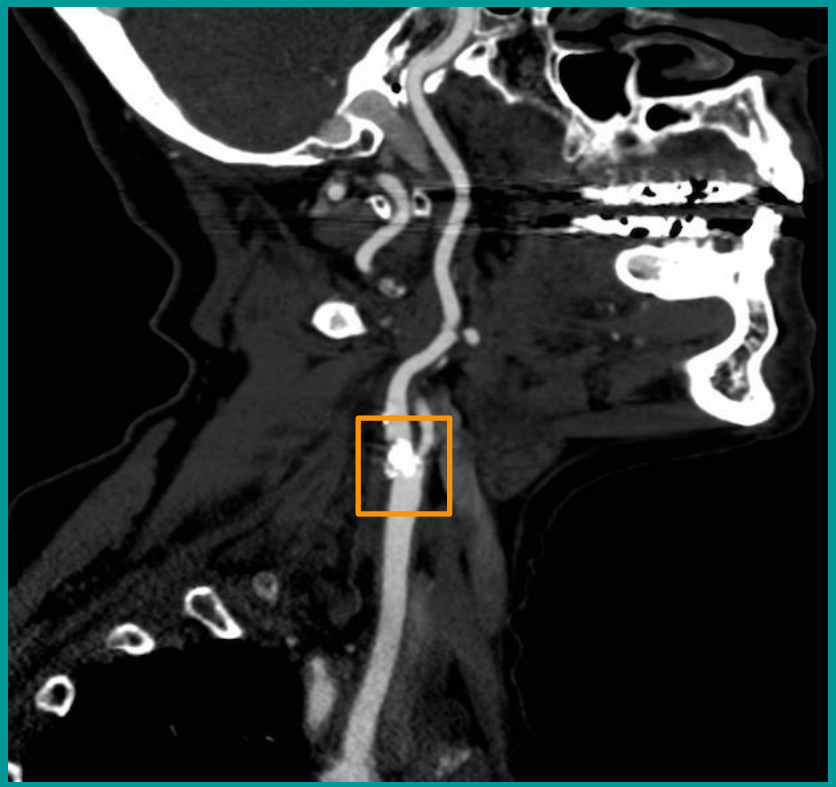
Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Companion Patient #1: CTA Reformat



PACS, BIDMC **C+ CTA Curved Reformat**

ICA showing calcified atherosclerotic plaque.



PACS, BIDMC **C+ CTA Curved Reformat**

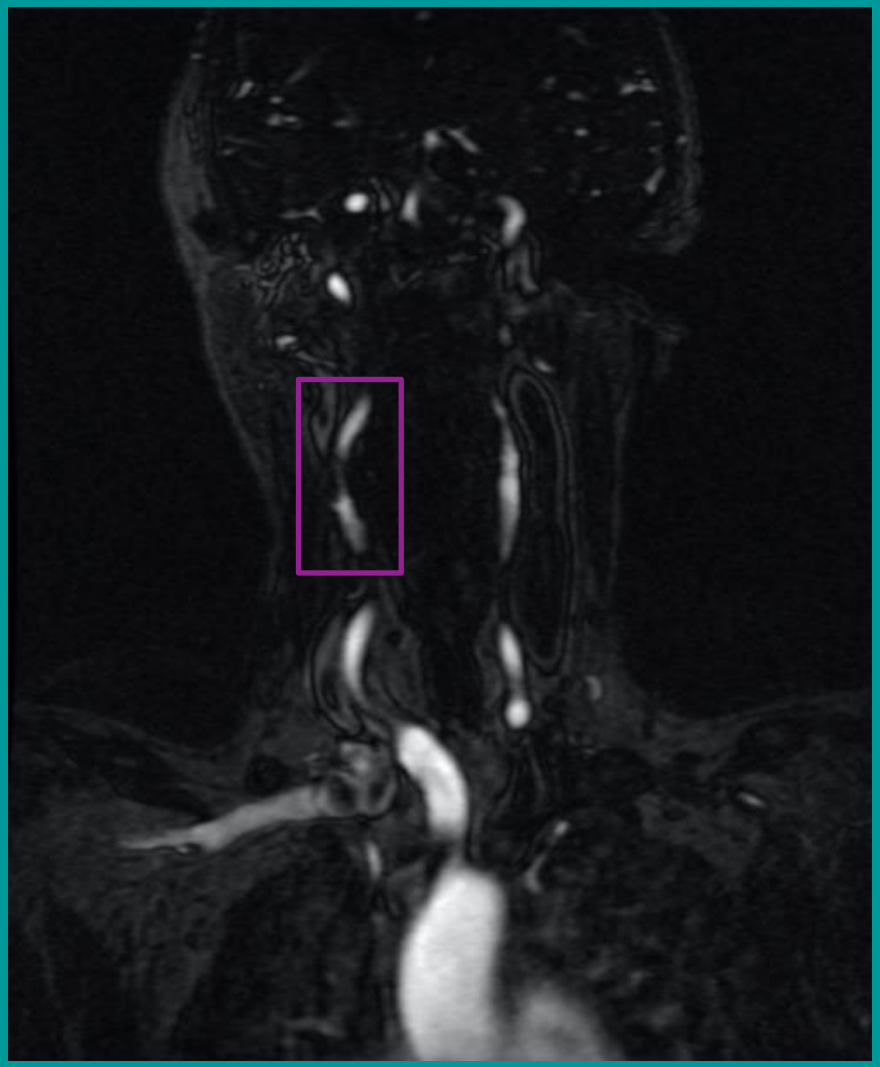
Right carotid bifurcation with calcified atherosclerotic plaque of the proximal ICA.

Companion Patient #2

- This is a 79 y/o woman with HTN and HLD who was found to have a right carotid bruit by her PCP.
- She underwent CDUS that showed severe (70-99%) stenosis of her right ICA.
- An MRA was obtained to further characterize her vascular anatomy.

Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Companion Patient #2: MRA



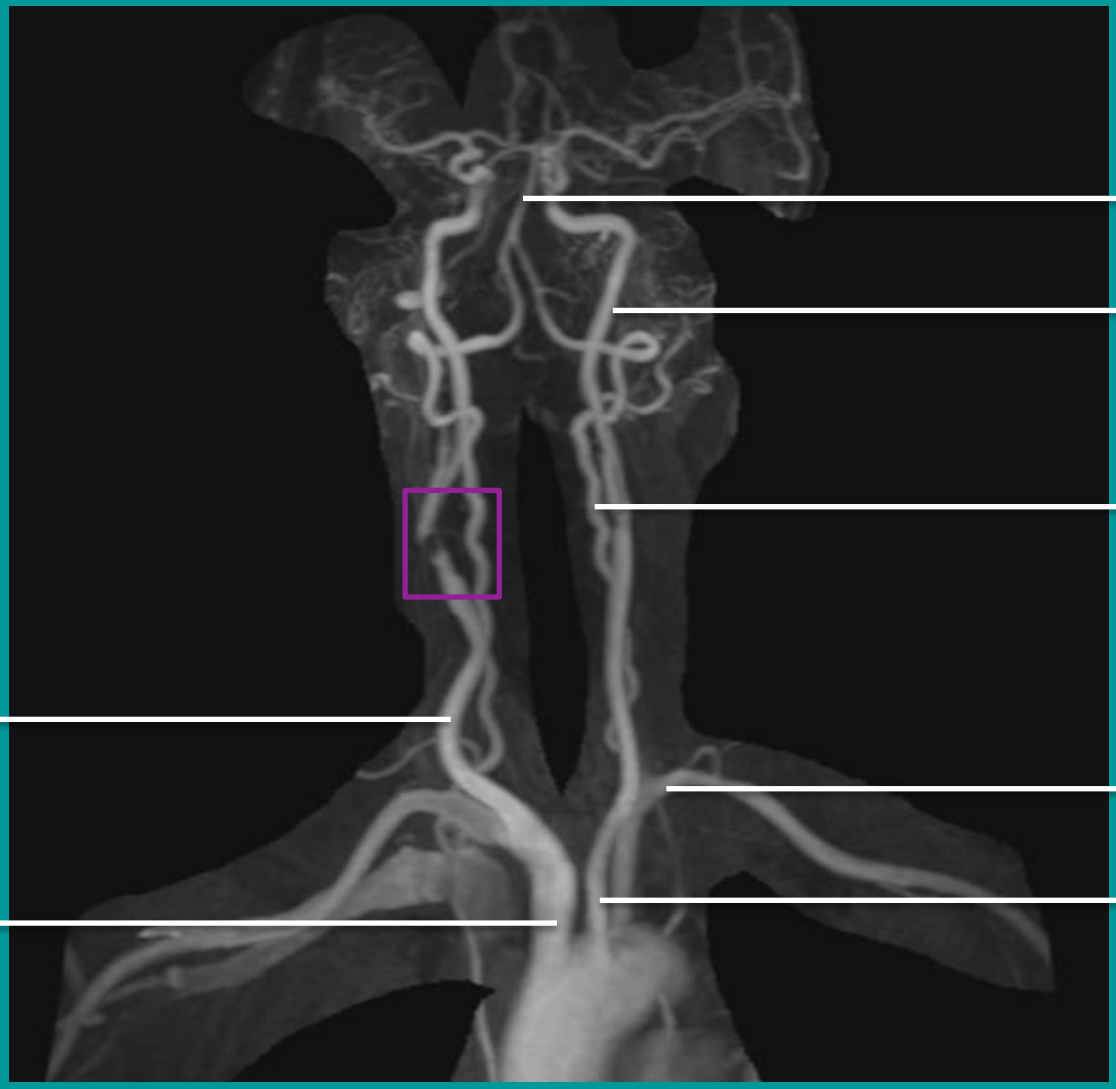
PACS, BIDMC **C+ T1 Weighted Dynamic MRA**

ICA showing approximately 85% stenosis.

Beth Israel Deaconess Medical Center
Gregory Parker, 2015
Gillian Lieberman, MD

Companion Patient #2: MRA Reformat

ICA showing severe, approximately 85% stenosis.



PACS, BIDMC

3D Projections of C+ T1 Weighted Dynamic MRA

ICA Stenosis: Treatment

- A large RCT (NASCET) found that carotid endarterectomy reduces risk compared to medical therapy alone*
  - Specific for symptomatic patients with 70-99% stenosis*
  - 2 year ipsilateral stroke risk of 9% with carotid endarterectomy vs. 26% with medical therapy*
- Society for Vascular Surgery recommends endarterectomy for most patients with:
  - Symptomatic carotid stenosis of 50-99% ǂ
  - Asymptomatic carotid stenosis of 60-99% ǂ

**North American Symptomatic Carotid Endarterectomy Trial Collaborators 1991*

ǂ *Ricotta 2011*

Outcomes for Presented Patients

- Our Patient AB
  - Symptomatic, 70-99% stenosis of right ICA by CDUS
  - Tx: Right Carotid Endarterectomy
- Companion Patient #1
  - Symptomatic, greater than 80% stenosis of right ICA by CTA
  - Tx: Right Carotid Endarterectomy
- Companion Patient #2
  - Asymptomatic, 70-99% stenosis of right ICA by CDUS, 85% stenosis of right ICA by MRA
  - Tx: Right Carotid Endarterectomy

Summary

- Learn the menu of tests available to assess for carotid artery stenosis
  - CDUS, CTA, MRA
- Review the arterial anatomy of the aortic arch and neck
  - Reviewed on companion patient #2 MRA
- Learn to recognize carotid artery stenosis on different imaging modalities
  - Seen on CDUS, CTA, and MRA
- Learn a framework for thinking about etiologies of ischemic neurologic symptoms
  - Large Vessel Atherothrombotic, Small Vessel Occlusive, Distant Embolic, Systemic Hypoperfusion
- Understand how radiologic assessment of carotid artery stenosis impacts patient management
  - Radiologic quantification of stenosis by NASCET criteria

Acknowledgements

- Matthew Del Guzzo, MD
- Ning Lu, MD
- Anthony Esparaz, MD
- Gillian Lieberman, MD
- Katie Armstrong

References

- ACR Appropriateness Criteria: Cerebrovascular Disease. American College of Radiology. Accessed on September 12, 2015, at https://acsearch.acr.org/docs/69478/Narrative/
- Caplan LR. Etiology, classification, and epidemiology of stroke. UpToDate. August 2015. Accessed September 12, 2015, at http://www.uptodate.com/contents/etiology-classification-and-epidemiology-of-stroke?source=search_result&search=Etiology+ischemic+stroke&selectedTitle=1%7E150.
- Furie KL, Hakan A. Initial evaluation and management of transient ischemic attack and minor stroke. UpToDate. August 2015. Accessed September 12, 2015, at http://www.uptodate.com/contents/initial-evaluation-and-management-of-transient-ischemic-attack-and-minor-stroke?source=search_result&search=evaluation+of+TIA&selectedTitle=1%7E150.
- Furie KL. Evaluation of carotid artery stenosis. UpToDate. January 2015. Accessed September 12, 2015, at http://www.uptodate.com/contents/evaluation-of-carotid-artery-stenosis?source=search_result&search=evaluation+of+carotid+stenosis&selectedTitle=1%7E150.
- Gnasso A et al. Association between intima-media thickness and wall shear stress in common carotid arteries in healthy male subjects. Circulation. 1996;94(12):3257
- Grant EG et al. Carotid artery stenosis: gray-scale and Doppler US diagnosis-Society of Radiologists in Ultrasound Consensus Conference. Radiology. 2003;229 (2): 340-6.
- Jaff MR et al. Imaging of the carotid arteries: the role of duplex ultrasonography, magnetic resonance arteriography, and computerized tomographic arteriography. Vasc Med. 2008;13(4):281.
- North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N. Engl. J. Med. 1991;325 (7): 445-53.
- Ricotta JJ et al. Updated society for vascular surgery guidelines for management of extracranial carotid disease. J Vasc Surg. 2011;54:e1–31.
- Wardlaw JM et al. Non-invasive imaging compared with intra-arterial angiography in the diagnosis of symptomatic carotid stenosis: a meta-analysis. Lancet. 2006;367(9521):1503.