TO CATCH A THIEF:
IMAGING OF SUBCLAVIAN STEAL

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AGENDA

- Introduction to our patient A.B.
- Anatomy review of aorta and branches
- CT imaging of our patient
- Anatomy and pathophysiology review of subclavian steal
- Duplex ultrasound principles
- Manifestations of subclavian steal on Duplex ultrasound
- Patient findings and summary
OUR PATIENT: A.B.

- 68 year old man
- History of poorly differentiated adenocarcinoma of the distal esophagus, now s/p stenting, chemotherapy (cisplatin and fluorouracil), and radiation
- Presented to the ED with several days of fever, chest pain, dyspnea
  - Chest pain mid-sternal and pleuritic, with no radiation to arms or abdomen
  - In the ED, discovered to be extremely hypotensive (96/67) relative to his normal
PAST MEDICAL HISTORY: A.B.

- 50 pack year history of smoking, recently 1 pack per day
- Documented history of excessive alcohol use, 6-8 beers per day
- Family history of thromboembolic events, etiology unknown
DIFFERENTIAL DIAGNOSIS (PER ED):

- Pulmonary embolism
- Septic shock
- Aspiration pneumonia
- Esophageal perforation
NEXT STEPS: A.B.

- Chest radiograph ordered to rule out pneumonia (most likely diagnosis)
A.B.: CHEST RADIOGRAPH - PA, UPRIGHT

- Pause to review film and continue to read findings
A.B.: CHEST RADIOGRAPH FINAL REPORT

- Negative / non-diagnostic.
A.B.: PHYSICAL EXAM

- Left arm was noted to be pale and cool
- Left radial pulse was significantly weakened
- Later, BP was retaken in other (right) arm and noted to be 156/49
- Remainder of exam non-contributory

→ CT angiogram performed to advance differential diagnosis
CLINICAL CONSIDERATIONS

- Asymmetric vascular insufficiency of the upper extremity may suggest pathology at the aortic arch or its branches.
- It is helpful to review the vascular anatomy of this region in order to better understand sources of pathology and interpret imaging.
ANATOMY OF THE AORTIC ARCH AND CIRCLE OF WILLIS

Image from The Netter Collections of Medical Illustrations, Volume 1, Part I: Nervous System. 2002.

Image from Children’s Hospital of Wisconsin, Birthmarks and Vascular Anomalies Clinic 2011.
A.B.: CT ANGIOGRAM OVERVIEW

- The (9) images to follow are a sequential series of images from the CT angiogram performed on our patient A.B.

- Imaging details:
  - Chest region
  - Coronal view
  - (+) Vascular contrast

- Images obtained from BIDMC PACS system
A.B.: CT ANGIOGRAM
A.B.: CT ANGIOGRAM
A.B.: CT ANGIOGRAM
A.B.: CT ANGIOGRAM
A.B.: CT ANGIOGRAM
A.B. CT ANGIOGRAM FINDINGS

- Pause to review the prior images and continue to view findings.
- The (9) images to follow are the same sequence as previously, now with relevant anatomy and findings labeled.
A.B.: CT ANGIOGRAM FINDINGS

Aortic Arch
A.B.: CT ANGIOGRAM FINDINGS

Origin of brachiocephalic trunk
Origin of left common carotid artery
A.B.: CT ANGIOGRAM FINDINGS

Origin of left subclavian artery
Substantial atherosclerotic plaque at proximate left subclavian artery. Note the absence of contrast distal to the plaque.
Substantial atherosclerotic plaque at proximate left subclavian artery. Note the absence of contrast distal to the plaque.
Substantial atherosclerotic plaque at proximate left subclavian artery. Note the absence of contrast distal to the plaque.
A.B.: CT ANGIOGRAM FINDINGS
A.B. CTA FINDINGS (PER RADIOLOGY REPORT)

1. No evidence of pulmonary embolism or acute aortic syndrome.

2. No esophageal extravasation of contrast or pneumomediastinum identified.

3. Bibasilar ground-glass opacities with nodular components, more prominent in the right base, are worsened than in the recent previous exam. Given short term progression this likely represents infection versus aspiration.

4. Complete occlusion of the left subclavian artery by a large calcified atherosclerotic plaque at its origin is incompletely evaluated in this exam but raises possibility for subclavian steal syndrome. Evaluation of differential upper extremity blood pressure should be performed.
CLINICAL IMPLICATIONS OF SUBCLAVIAN ARTERY STENOSIS

- Stenosis of the left subclavian artery can cause hypoperfusion of downstream tissue.
- Degree of hypoperfusion depends on tissue demand, i.e. exercise of ipsilateral arm.
- Collateral blood supply, a routine physiologic compensatory mechanism, can help ameliorate these effects. Collateral supply can come from:
  - Contralateral vertebral artery, via communication at basilar artery (primary source)
  - Circle of Willis, with retrograde flow down basilar artery (secondary source)
- This compensation, from sources which ordinarily supply the brain, is not without its own drawbacks.
- The following slides illustrate the pathophysiological effects of altered blood flow in the setting of subclavian artery stenosis.
DEFINITIONS

• Subclavian Steal: Subclavian artery stenosis proximal to the origin of the vertebral artery. Associated with flow reversal in the ipsilateral vertebral artery.

• Subclavian Steal Phenomenon (SSP): A radiologic diagnosis, based on imaging of flow directionality.

• Subclavian Steal Syndrome (SSS): A clinical diagnosis, with neurological symptoms as a result of deficient blood flow to the posterior cerebral circulation.

→ See the slides to follow for illustrations of relevant anatomy.
CLASSICAL PHYSIOLOGY OF SUBCLAVIAN STEAL

- Blood flows from areas of high pressure to areas of lower pressure.
- In SSP, the subclavian artery distal to the obstruction, and its branches (including the L vertebral artery), have low pressure.
- High pressure blood in the contralateral vertebral artery “sees” the low pressure in the L vertebral artery where they meet (at the basilar artery), and flows in retrograde fashion down the L vertebral artery.
- This is the classical understanding of SSP physiology.

**CONTROVERSY RE: CIRCLE OF WILLIS INVOLVEMENT**

- Atherosclerotic disease rarely occurs in the proximal subclavian artery in isolation.

- The classical notion of SSP states that compensatory blood flow comes only from the contralateral vertebral artery. As such, when the contralateral vertebral artery also has some stenosis, one would expect the patient to exhibit neurological symptoms of posterior circulation deficit.

- However, Lord et al disputed this belief, suggesting that the anterior circulation (carotid arteries via Circle of Willis) can compensate for posterior circulation deficits in some patients. Their study results are summarized on the next slide.

In patients whose contralateral vertebral arteries were stenosed, blood from the carotid arteries (via the Circle of Willis) compensated for the subclavian deficits and patients had no neurological symptoms.

This suggests that the anterior circulation can and does compensate for the deficiencies of SSP.

In patients with contralateral vertebral artery stenosis AND persistent fetal Circle of Willis (in which the anterior circulation including the posterior cerebral artery is relatively isolated from the posterior circulation)—meaning the anterior circulation is not able to compensate—patients had neurological symptoms.

This suggests that the Circle of Willis is the only other significant compensatory mechanism for the deficiencies of SSP.

This is illustrated on the following slide.
CIRCLE OF WILLIS
COMPENSATION OF SUBCLAVIAN STEAL

Image adapted from The Netter Collections of Medical Illustrations, Volume 1, Part II: Nervous System. 2002.
CORONARY-SUBCLAVIAN STEAL

- Often in coronary artery bypass graft surgeries, the internal thoracic artery (formerly called the internal mammary artery) is surgically anastomosed to the coronary arteries to provide an alternate source of blood flow.
- Of note, the internal thoracic artery is a proximal branch of the subclavian artery similar to the vertebral artery.
- With proximal subclavian artery stenosis, the ITA experiences an analogous reversal of flow, this time “stealing” blood from the heart.

Common carotid artery

Internal thoracic artery

A.B. HISTORY CONTINUED

- Denies claudication of left upper extremity.
- Denies blurred vision, headache, loss of consciousness, diplopia, vertigo, dizziness.
- Per radiology report: “Dense calcification was also seen at the level of occlusion in the non enhanced chest CT from September 23, 2013, suggesting chronicity.”
- Patient is asymptomatic, so no current therapy needed.
- However, further evaluation of pressure differential needed. Carotid/vertebral duplex ultrasound is most useful to evaluate directional flow.
DUPLEX PRINCIPLES

- Duplex Doppler ultrasound is a form of Doppler which combines:
  - Color flow Doppler - simultaneous display of anatomy and flow dynamics
  - Spectral Doppler - graphically represented flow, with velocity v. time
- Doppler velocity waveforms vary substantially depending on the intrinsic nature of the vasculature being measured.
  - Artery versus vein
  - High resistance versus low resistance
- Vertebral artery is low-resistance and typically has a monophasic waveform.
COMPANION PATIENT #1:
NORMAL V A D U P L E X U L T R A S O U N D

BLOOD FLOW DYNAMICS

- Basic physics principles can offer insight into the manifestation of subclavian stenosis.
- When fluid travels through a smaller area and flow is constant, its velocity increases (Q=AV). Thus, blood traveling through an area of stenosis travels more quickly relative to normal.
- According to the Bernoulli Principle, when fluid moves at higher velocity, it exerts lower pressure. (Note: this is the same principle employed in creating lift on an airfoil to help aircraft fly.) Thus, the fast moving blood distal to a stenosis is at lower pressure than usual for that area.
- During systole, flow is greatest, therefore velocity is greatest, therefore pressure is lowest distal to the stenosis.
- As illustrated on the next slide, this can have important physiological effects.
As discussed previously, pressure distal to the subclavian stenosis is lowest during systole.

Because blood flows from areas of high to low pressure, blood flow in the left vertebral artery can favor transient reversal during systole.

When superimposed on otherwise forward flowing blood, this change in pressure gradient manifests as a transient slowdown in blood flow velocity.

During diastole, when subclavian artery pressure normalizes, left vertebral artery returns to normal full velocity antegrade flow.

higher velocity = lower pressure (Bernoulli Principle)

narrow space = higher velocity (Q = AV)
COMPANION PATIENT #2: TYPE 1 V A WAVEFORM

- These transient slowdowns in flow, caused by transient drops in subclavian artery pressure, manifest on spectral Doppler ultrasound as a “notch” in the normal monophasic waveform.

- Recall that spectral Doppler ultrasounds plot velocity versus time.
- Each apex of the waveform indicates points of maximal velocity.

SCHEMATIC PHYSIOLOGY OF MODERATE SUBCLAVIAN STENOSIS

- The degree of vertebral artery transient flow slowdown during systole depends on the degree of stenosis.
- Based on the principles discussed, greater stenosis results in greater transient flow velocity reduction.

The greater degree of transient slowdowns in flow manifest on spectral Doppler ultrasound as a deeper notch in the normal monophasic waveform.

With even greater stenosis, the pressure differential can be so great as to cause a transient stoppage of flow during diastole, as regular forward flow is matched by a gradient favoring reversed flow.

This manifests on spectral Doppler ultrasound as a deep notch reaching the x axis (the point of zero velocity).

COMPANION PATIENT #5: TYPE 4 V A WAVEFORM

• As even greater stenosis causes a greater pressure differential, flow transiently reverses in the vertebral artery.

• This is represented on the spectral Doppler by regions of negative velocity during systole.

COMPANION PATIENT #6: FULL STEAL WAVEFORM

- With full obstruction of the proximal subclavian artery, pressure distal to that point drops to zero, creating a maximal pressure gradient between there and the basilar artery.
- There is no source of forward flow in the vertebral artery.
- The spectral Doppler displays full retrograde flow in a monophasic pattern.

APPLICATIONS

With this understanding of the fundamentals of Duplex ultrasound and the manifestations of the subclavian steal phenomenon, let us return to our patient A.B. and interpret his Duplex ultrasound findings.
OUR PATIENT: A.B. RIGHT V A DUPLEX ULTRASOUND

Pause to review this image and continue to read the interpretation.
INTERPRETATION : A.B. **RIGHT V A DUPLEX ULTRASOUND**

- The spectral component shows a monophasic waveform, with no notches, fully above the x-axis.
  - This indicates full forward flow with no transient slowdowns.
  - This is a normal study
- The color flow component shows normal anatomy with a vertebral artery colored red.
  - This indicates, again, normal forward flow.
OUR PATIENT: A.B. LEFT V A DUPLEX ULTRASOUND

2D
62%
C 50
P Low
Gen
CF
74%
3000Hz
WF 165Hz
Med

PAWS, BIDMC
• Pause to review this image and continue to read the interpretation
INTERPRETATION: A.B. LEFT VA DUPLEX ULTRASOUND

- The spectral component shows a largely monophasic waveform, with the systolic component below the x-axis and the diastolic component hugging the x-axis.
  - This indicates substantial retrograde flow during systole, and slight-to-no forward flow during diastole.
  - This study shows near-full subclavian steal physiology.
- The color flow component shows normal anatomy with a vertebral artery colored blue.
  - This indicates retrograde flow in the left vertebral artery.
FINDINGS:

- RIGHT: B-mode images show bulky, heterogeneous plaque throughout the distal common carotid and carotid bifurcation. Common carotid waveform is within normal limits and has a velocity of 1.17 m/sec. ICA velocities are 0.87/0.19. The ECA velocity is 1.67. The ICA/CCA ratio is 0.7. By velocity criteria, this correlates with a 1 - 39% stenosis.

- LEFT: B-mode images show bulky, heterogeneous plaque at the common carotid and carotid bifurcation. The common carotid waveform is within normal limits and has a peak velocity of 1.15 m/sec. The ICA velocities are 1.74/0.29. The ECA velocity is 1.78. The ICA/CCA ratio is [1.5]. By velocity criteria, this correlates with a 1 - 39% stenosis.

See next slide for reference table to interpret the carotid artery findings.
### ICA DOPPLER GUIDELINES

#### Relation between increased blood velocity and degree of stenosis

<table>
<thead>
<tr>
<th>Diameter of stenosis (%)</th>
<th>Peak systolic velocity* (m/s)</th>
<th>Peak diastolic velocity* (m/s)</th>
<th>Internal: common carotid artery velocity ratio†</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-39</td>
<td>&lt;1.1</td>
<td>&lt;0.45</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>4-59</td>
<td>1.1-1.49</td>
<td>&lt;0.45</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>60-79</td>
<td>1.5-2.49</td>
<td>0.45-1.4</td>
<td>1.8-3.7</td>
</tr>
<tr>
<td>80-99</td>
<td>2.5-6.1</td>
<td>&gt;1.4</td>
<td>&gt;3.7</td>
</tr>
<tr>
<td>&gt;99 (critical)</td>
<td>Extremely low</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Measured in lower part of internal carotid artery

†Ratio of peak systolic velocity in internal carotid artery stenosis relative to proximal measurement in common carotid artery

A.B. DUPLEX ULTRASOUND FINAL REPORT CONT’D.

- **FINDINGS:**
  - The right vertebral artery has antegrade, monophasic waveform. The left vertebral artery has reversed flow consistent with subclavian steal physiology. The left brachial waveform is accordingly monophasic.
  - **IMPRESSION:** Diffuse distal common carotid and carotid bifurcation plaque with no significant stenosis. Reversal of flow is seen in the left vertebral artery consistent with a known subclavian occlusion.
A.B. SUMMARY

- This patient, A.B., presented with a prototypical feature of subclavian steal phenomenon—substantial blood pressure differential between the two arms.

- A.B. did not present with other signs/symptoms typical of subclavian steal. Because of its long-term nature—indicating gradual development over time—compensatory mechanisms likely developed, which may explain this.

- In contrast, subclavian steal syndrome typically presents as posterior circulation deficits (syncope, vertigo, tinnitus).

- Once SSS is identified, the best way to definitively characterize it and assess directional blood flow is through duplex Doppler ultrasound.

- Ultimately, A.B. was diagnosed with and treated for pneumonia. He had no intervention for his asymptomatic subclavian stenosis.
REFERENCES


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