Blood Flow and the Colorado River:

A Lighthearted Look at Hemodynamics

Rob Daigle, BA, RVT, FSVU, FSDMS

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"Back in the Day"

Images by R. Daigle

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Honey, Can I go Kayaking with the Boys?

Image source unknown

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Kelly- Training for Future Grand Canyon Runs

Images by R. Daigle

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Kelly - Grand Canyon-2011 Kristin –Gr. Canyon 2018

Images by R. Daigle

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Raft Styles: Paddle Rafting

https://grandcanyonwest.com/colorado-river-rafting-with-the-hualapai-

8

Raft Styles: Motorized Commercial Raft (pay to play)

https://grandcanyon.com/tours/west-canyon-tours/one-day-whitewater-rafting/

9

Raft Styles: Multi-day Private Expedition Rafting

18 ft. oar rafts

All Images by R. Daigle

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In Vascular Ultrasound

"We determine the presence, absence, and severity of vascular disease based on Doppler-demonstrated flow patterns."

Rob Daigle, circa 2007

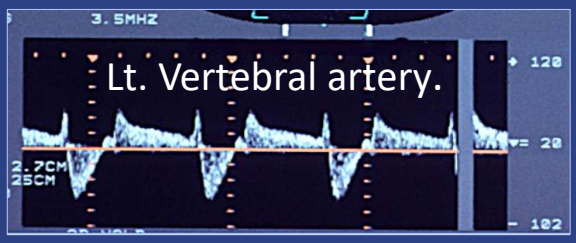

Image by R. Daigle

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Images by R. Daigle

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Row like a Slave, or…

https://www.theguardian.com/film/2019/nov/18/ben-hur-film-charlton-heston-60th-anniversary

Photograph: Allstar/MGM

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Long & Straight = Laminar and Parabolic flow

Images by R. Daigle

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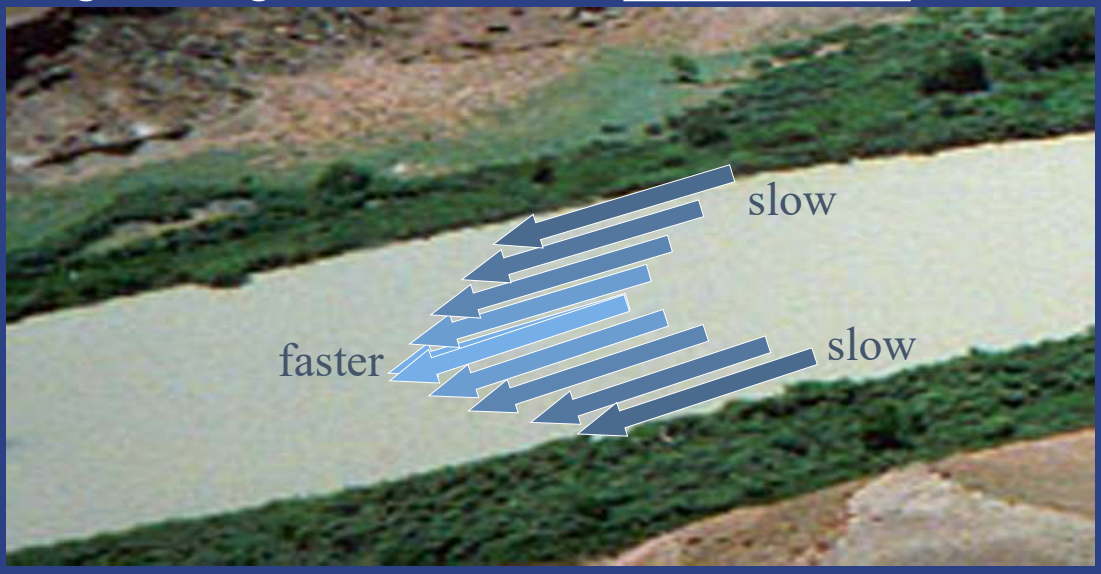
Long & Straight = Laminar and Parabolic flow



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Parabolic Flow in a Stream

Image by R. Daigle

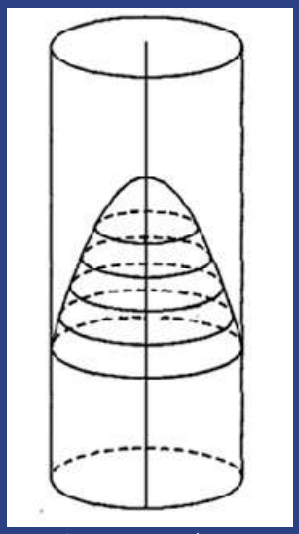

Image source unknown

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Curve- Laminar, but not Parabolic

Google Maps

Image by R. Daigle

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Laminar and Parabolic Flow

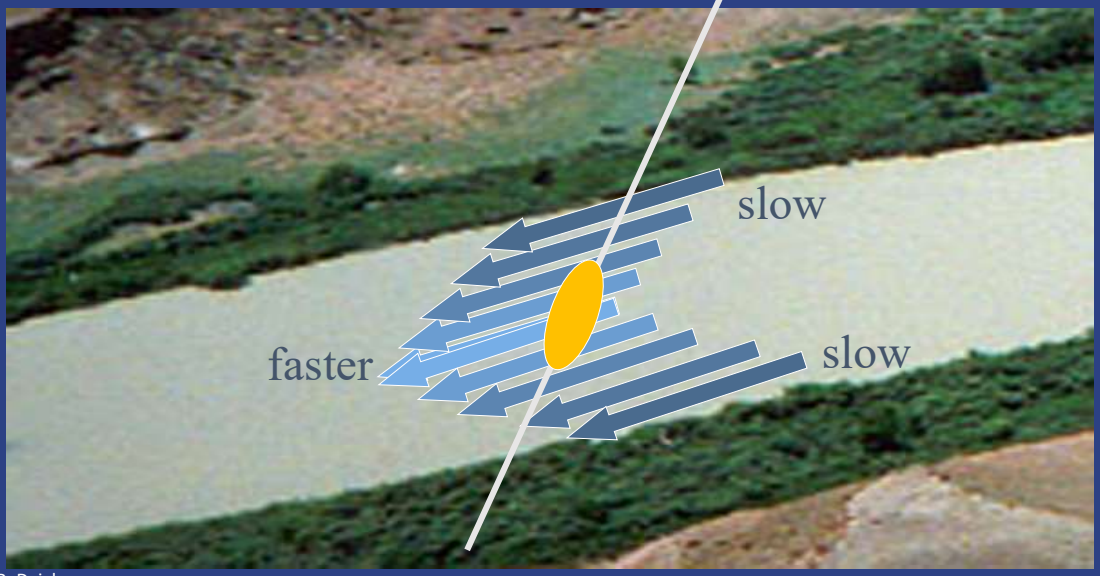

Image by R. Daigle

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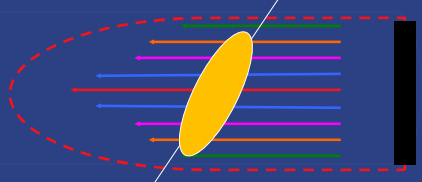
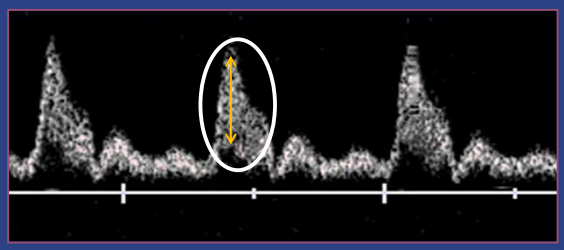
Spectral Waveforms Demonstrate Laminar and Parabolic Flow

Large sample volume- lots of lanes of flow



Large SV
SV 4 mm

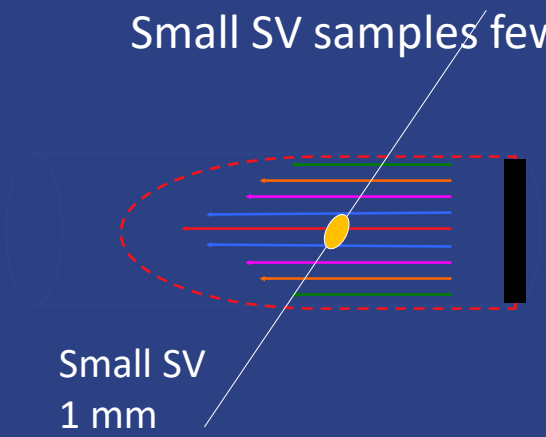


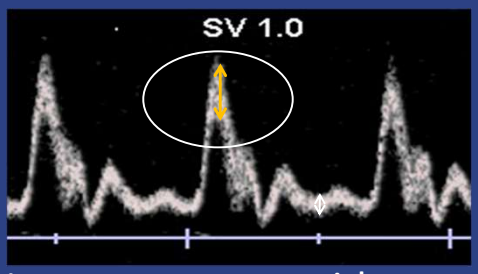
Wide spectrum-
spectral broadening

20

Spectral Waveforms Demonstrate Laminar and Parabolic Flow

Small SV samples fewer "lanes of flow





Narrow spectrum with minimal spectral broadening

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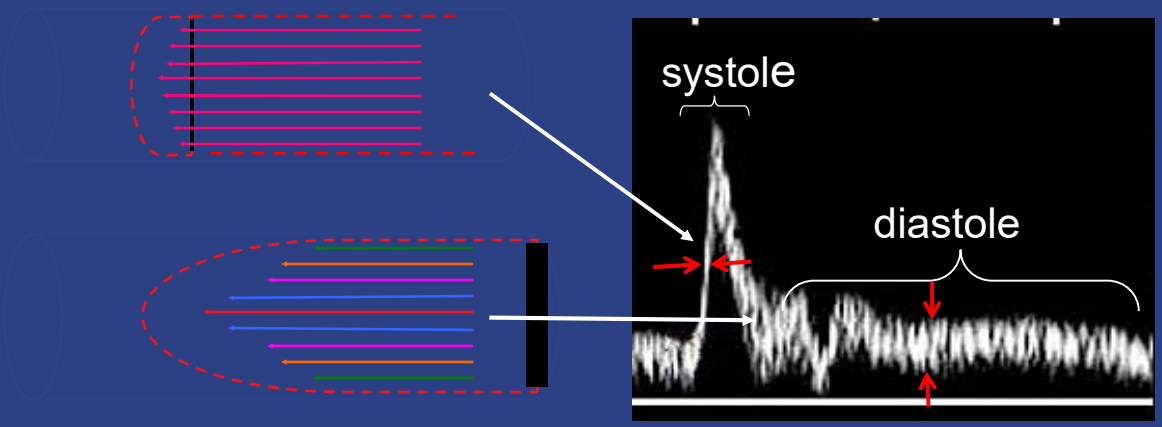
"Plug" flow occurs in systolic acceleration

SYSTOLE = "plug" flow, narrow spectrum



DIASTOLE = parabolic flow, wider spectrum

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Original (outdated) carotid criteria relied on spectral broadening.

- A. Normal
- B. 1-15%
- C. 16- 49 %

Based on spectral broadening

- D. 50-79%: peak syst. frequency > 4.0 KHz (≥125 cm/s)
- D+. 80-99%: end dias. frequency > 4.5 KHz (≥140 cm/s)
- E. Occluded. No ICA signal, CCA diastolic flow to zero

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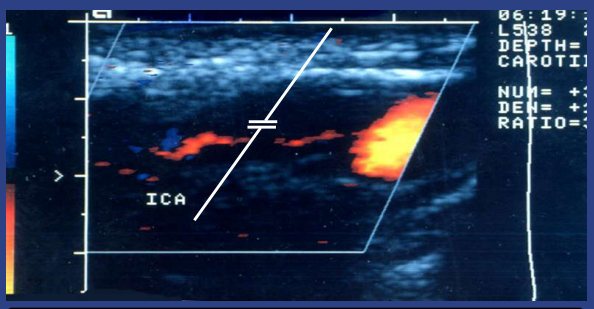
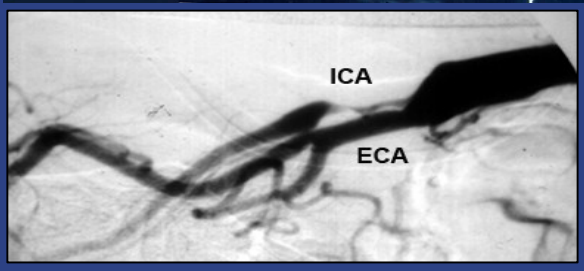
The "Geographic Miss"

- Residual lumen in a >90% stenosis is < 1 mm
- A small (1mm) sample volume may miss the residual lumen
- Low velocity may be missed with color Doppler





All Images by R. Daigle

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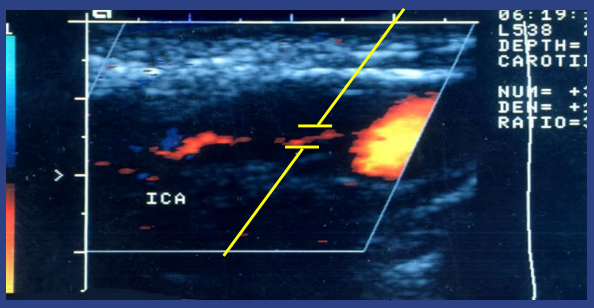
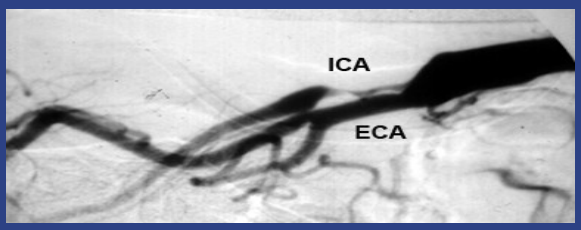
Avoid the "Geographic Miss"

- A 3-4 mm SV facilitates sampling of residual lumen in tight stenoses
- Color PRF must be set low





Images by R. Daigle

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Non-laminar Flow

Image by R. Daigle

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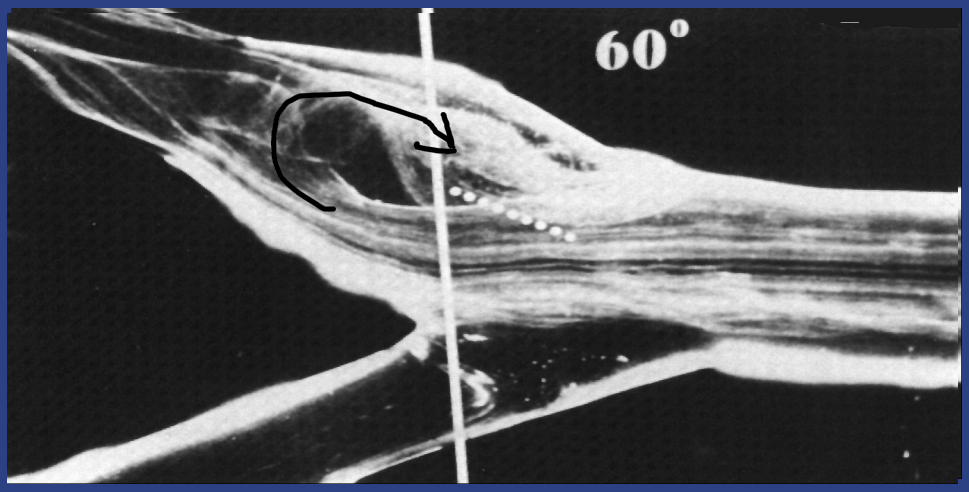
Helical Flow in Carotid Bulb



Ku, D N and Giddens, DP. Pulsatile flow in a model carotid bifurcation. Arterioscler Thromb Vasc Biol. 1983;3:31-39

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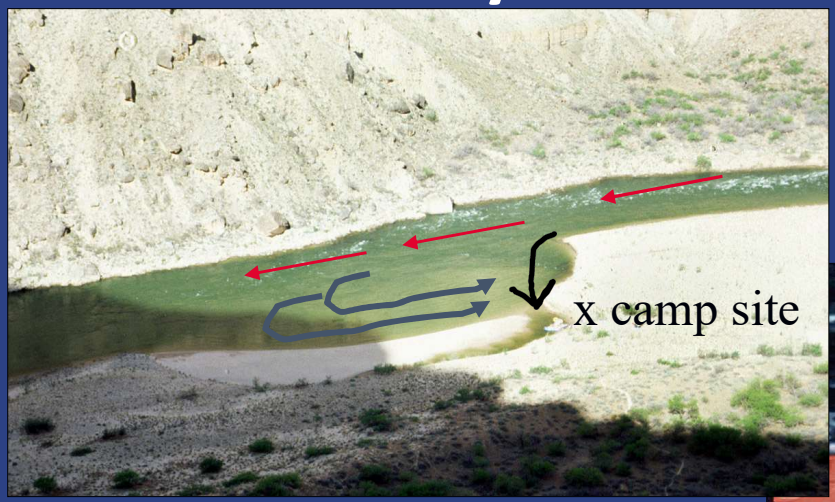
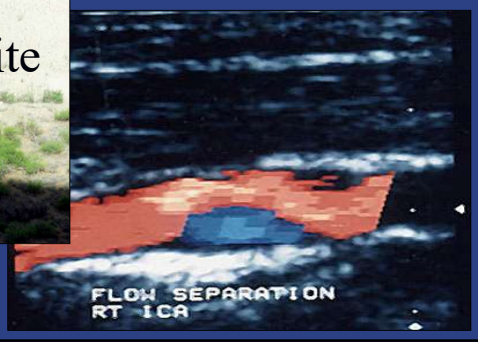
Eddy Current





Images by R. Daigle

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Flow reversal in a “hole”

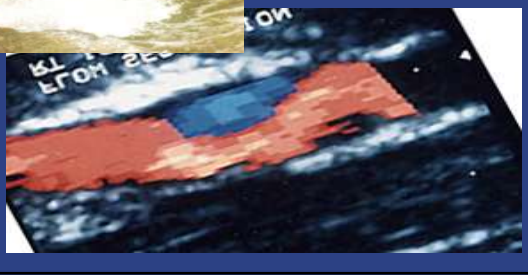

Image by R. Daigle

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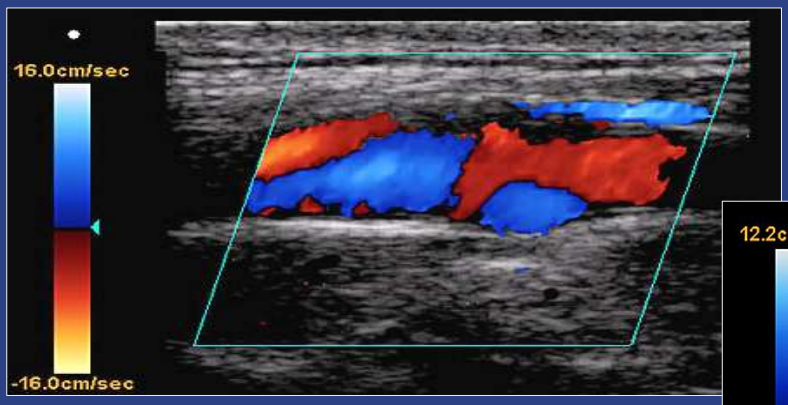
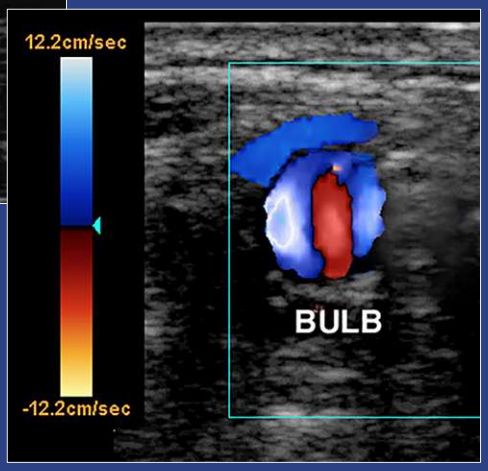


Transverse



Normal Helical
ICA bulb flow

AI Images by R. Daigle

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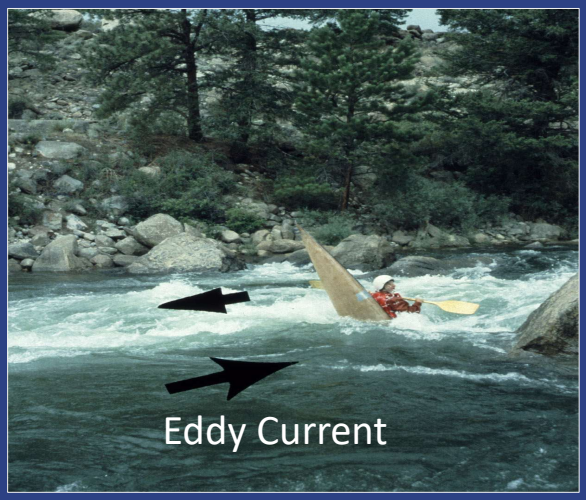
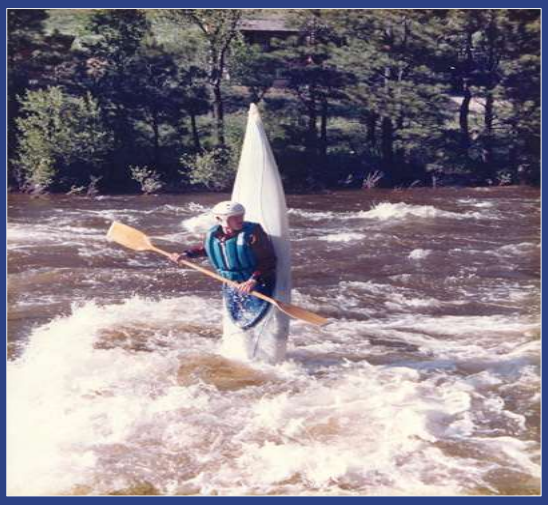
Flow Separation: Playing the Seams





All Images by R. Daigle

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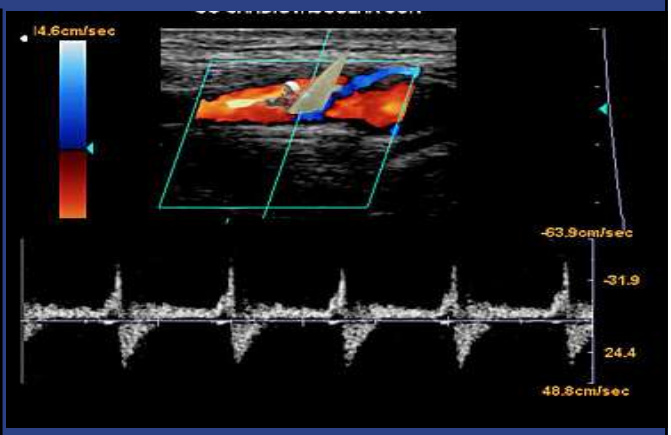
Flow Separation



Normal flow pattern in ICA "bulb"

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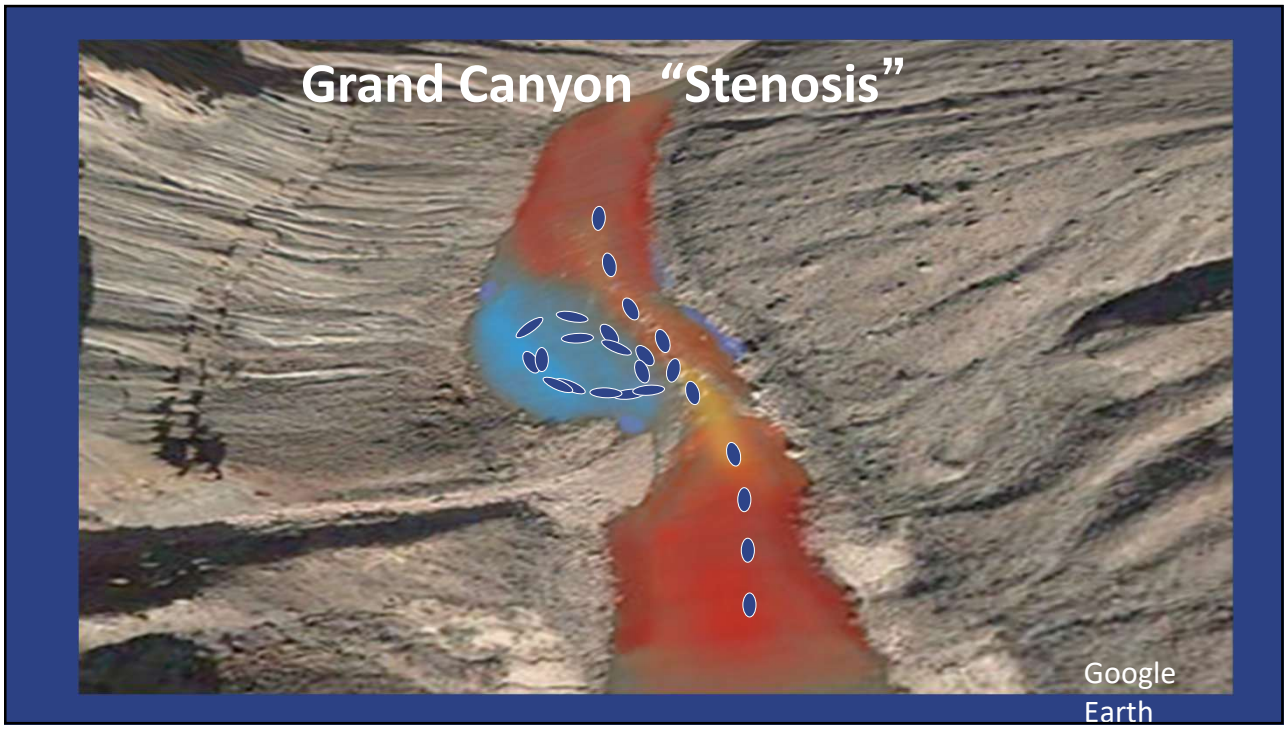

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The "Room of Doom"
Westwater Canyon- Colorado River

Skull Rapid Class 4 (1-6 whitewater scale)

Image by R. Daigle

Image by R. Daigle

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Room of Doom

Goggle Earth

https://www.youtube.com/watch?v=JhWtGeGYws

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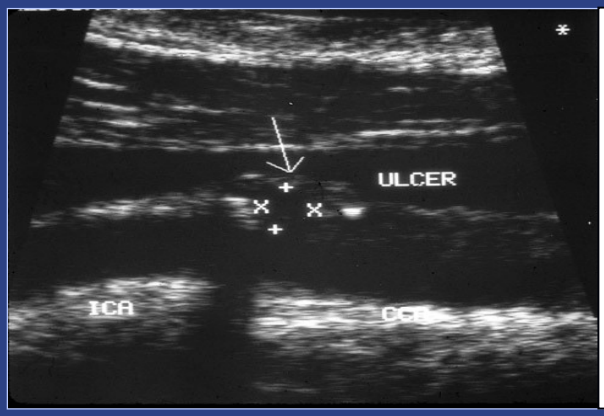
Carotid Plaque Ulceration: "Room of Doom"



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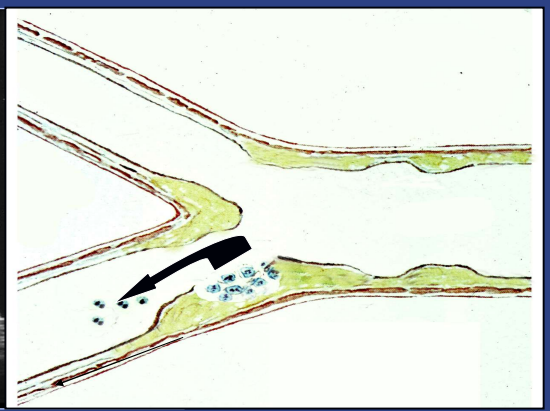

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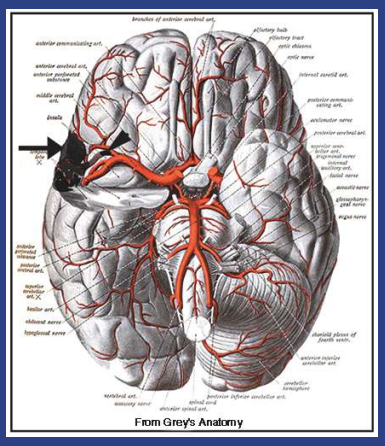
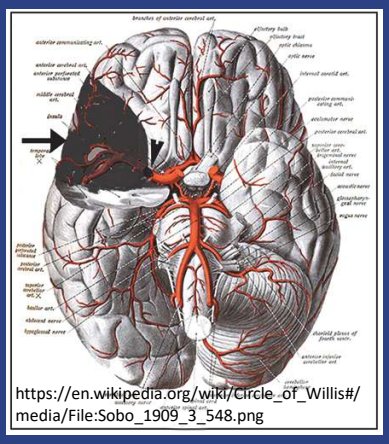
Infarction in lateral hemisphere-middle cerebral artery distribution



Small Emboli-
Small Infarction



Large Emboli-
Large Infarction

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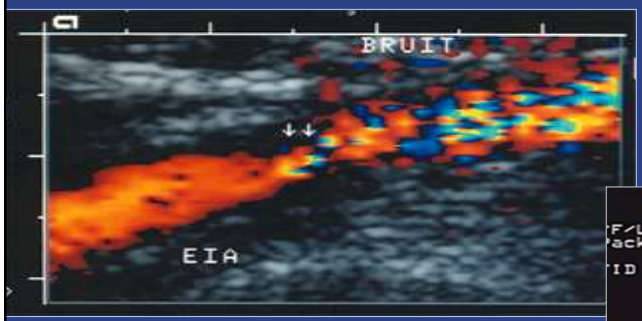
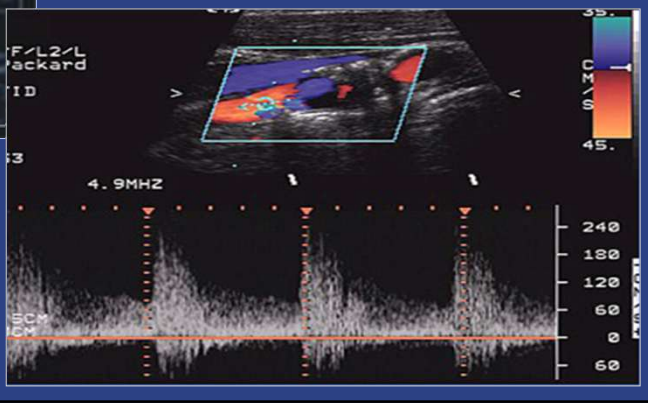
Turbulence, What is Turbulence??



Disrupted laminar flow



Weird colors and lousy waveforms !

Images by R. Daigle

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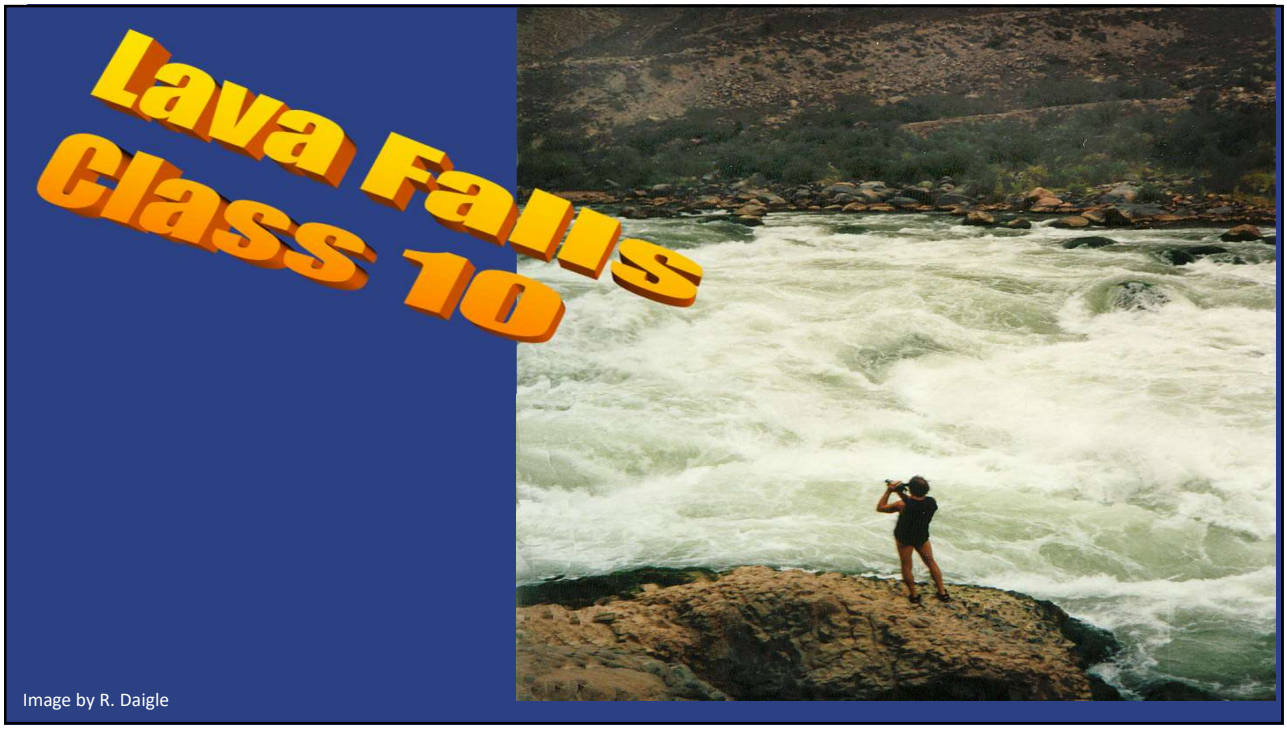

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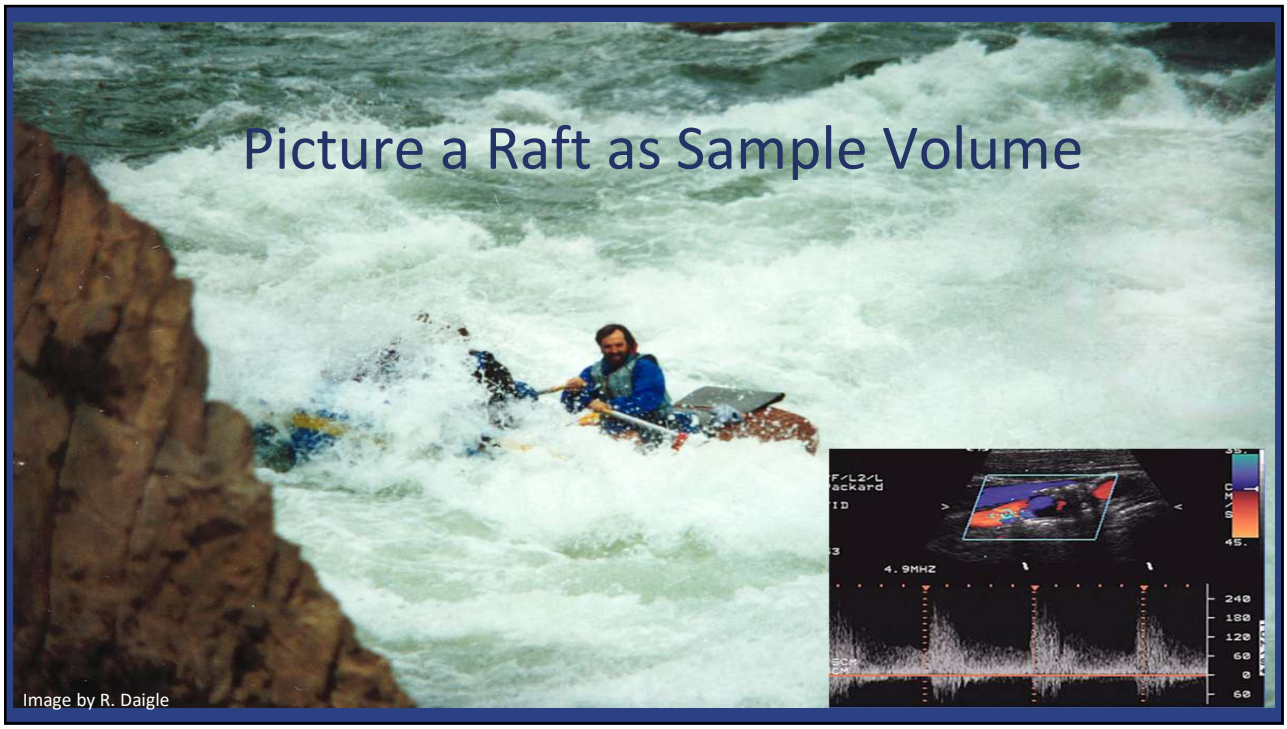

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https://www.youtube.com/watch?v=g0V_g0gGxaA

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Blood Flow Volume

River Volume

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Colorado River in GC

Lake Powell
Glen Canyon Dam

https://en.wikipedia.org/wiki/Glen_Canyon_Dam#/media/File:Glen_Canyon_Dam_and_Bridge.JPG

Daily volume discharge variation: 7,000 - 19,000 CFS

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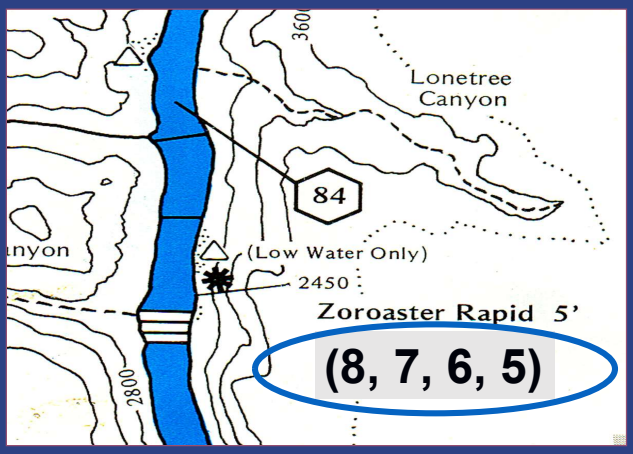
Difficulty Rating (1-10) Based on Flow Volume



Belknap's Waterproof Grand Canyon River Guide -Westwater Books 2015

Image by R. Daigle

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Crystal Rapid- Class 10
Flow 28,000 CFS

Image by R. Daigle

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Crystal Rapid- Class 10+, 1983-Dam Release- 93,000 CFS

photographed by Curt Smith

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Cerebrovascular system is a relatively "steady-state" system

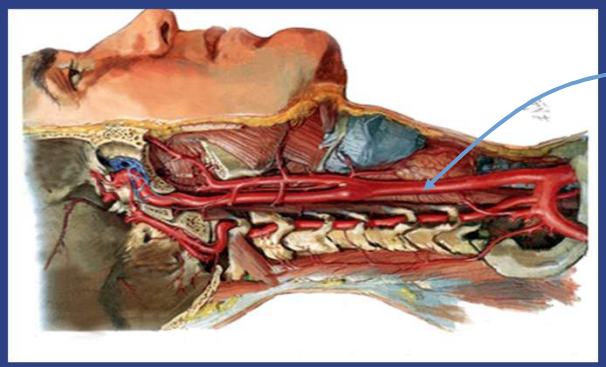

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Image by R. Daigle

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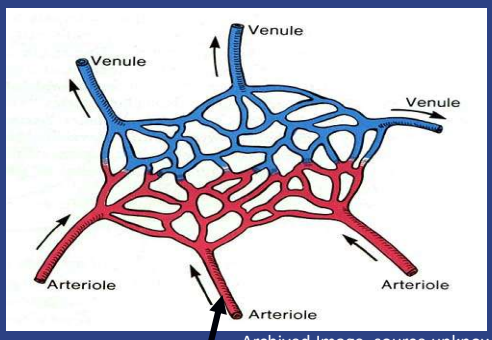
Normal Lower Arterial Waveform-Resting

Image by R. Daigle

SFA Multiphasic Waveforms



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Vasoconstriction at rest

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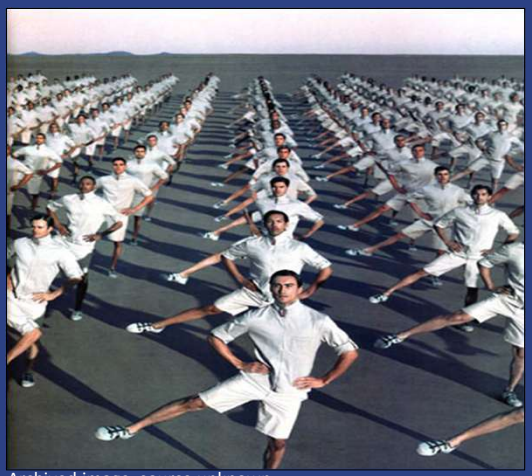
Arterioles and Flow Demand



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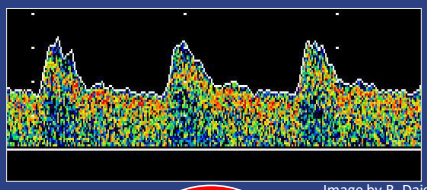

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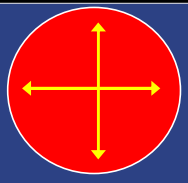

Vasodilation during exercise

5-10-fold increase in blood volume with exercise

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Poiseuille's Equation Modified

$$Q = \frac{\Delta P \, \pi \, r^4}{R}$$

Q = flow
ΔP = pressure gradient
π = pi (3.14)
r = vessel radius
R = resistance (length x viscosity)

Jean Leonard M. Poiseuille, 1797-1869, French physician and physicist

$$R \times Q = P$$

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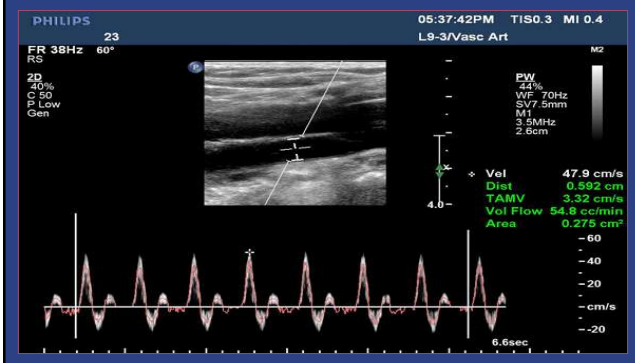
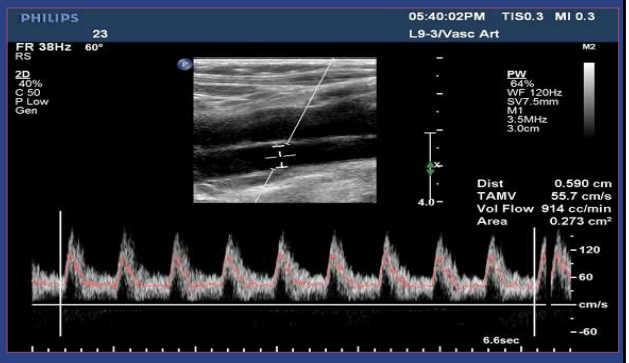
Popliteal artery volume at rest & post-exercise



Vol. 55 ml/min.



Vol. 914 ml/min.

R ↓ x Q ↑ = ankle P no change

Images by R. Daigle

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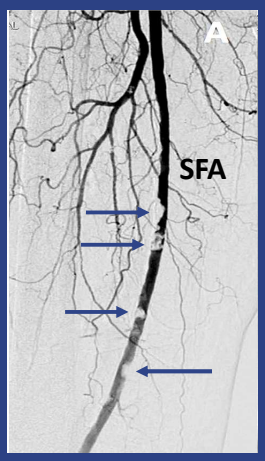
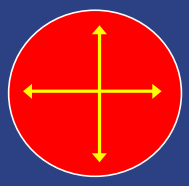
Patients with Occlusive Disease



Yokoi Y. Basics of Angiography for Peripheral Artery Disease. Angiography and Endovascular Therapy for Peripheral Artery Disease, March 2007. InTech. Available at: http://dx.doi.org/10.5772/67177



Arteriolar vasodilation during exercise

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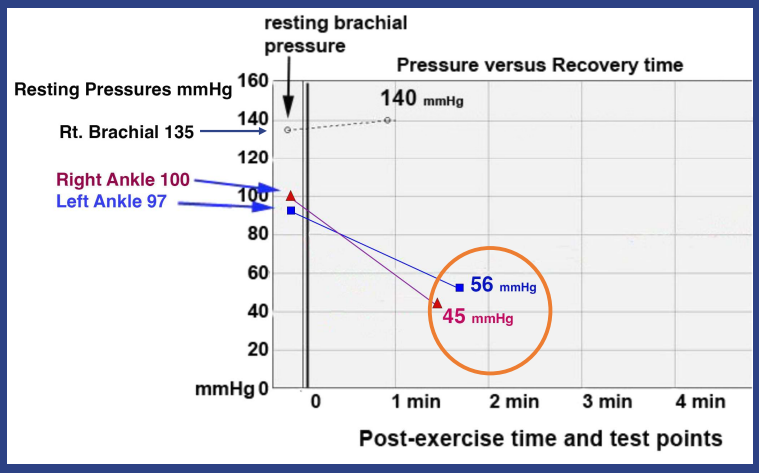
Patients with PAD - Exercise



R ↓ x Q ↓ = ankle P ↓

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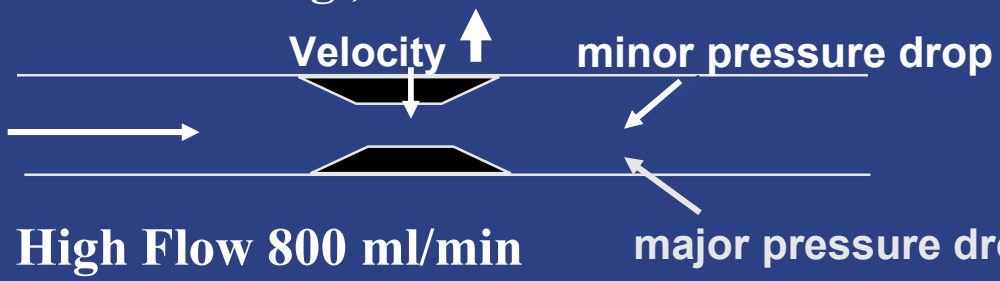
Poiseuille's Law (2nd part)

Blood volume change through a stenosis impacts distal perfusion

1. **Low Flow e.g., 55 ml/min**



2. **High Flow 800 ml/min**

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Patient: HK

- 59-year-old female
- Bilateral leg claudication after 100 yards
- Hx of MI, TIA
- Hx repaired dissecting thoracic aortic

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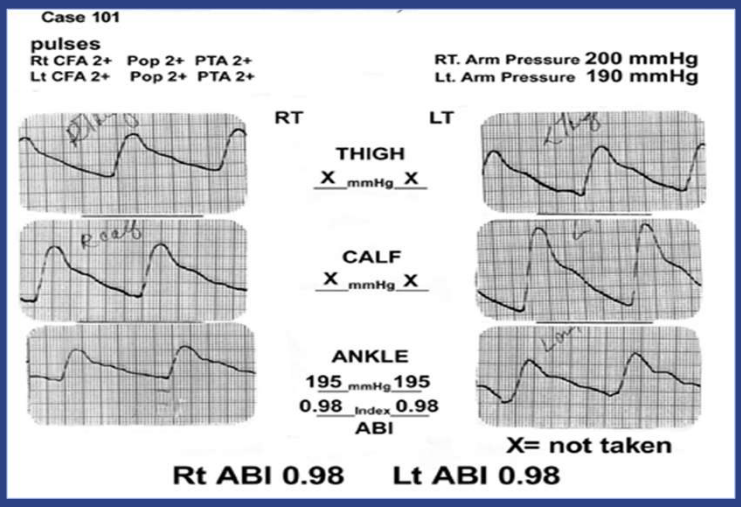
Pt. HK Resting Exam-Normal



Rt. ABI 0.98 Lt. ABI 0.98

Image by R. Daigle

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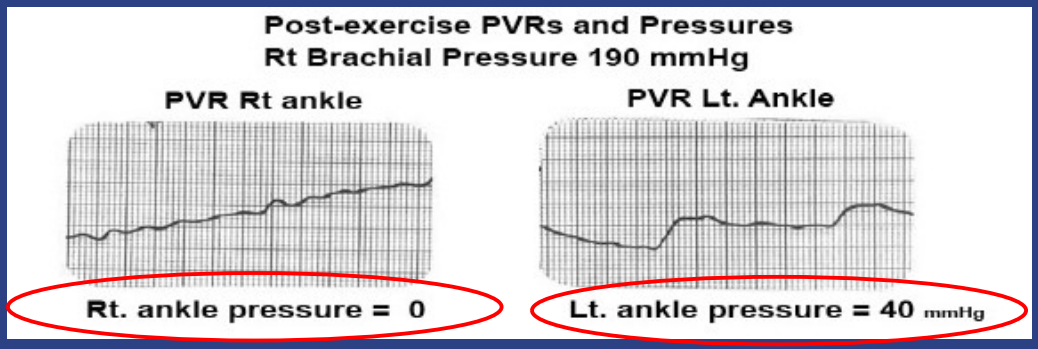
Post-exercise Treadmill Stress

- Treadmill 1.5 Mph, 10 % grade
- Bilateral leg fatigue limited walking to 1 min. 25 sec.



Rt. ankle pressure: 0 mmHg Lt. ankle press: 40 mmHg

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Pt. HK, Aortic Dissection

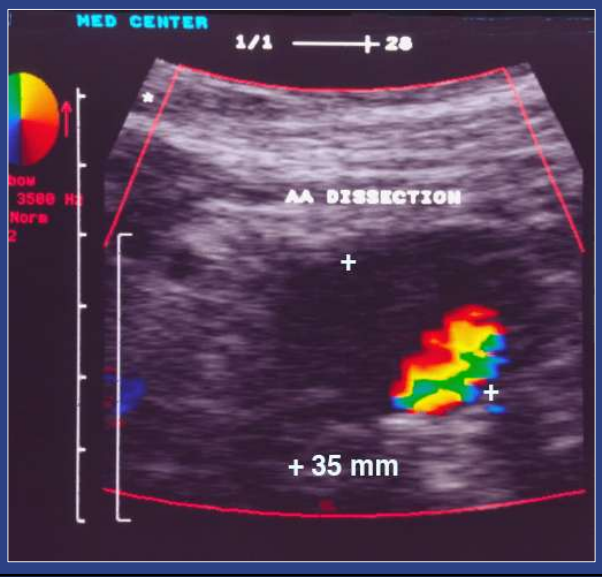

Image by R. Daigle

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Poiseuille's Equation/Law

1. $$Q = \frac{\Delta P \, \pi \, r^4}{8 \, \eta \, L}$$

   Small increase in vessel radius = large increase in volume

2. The pressure gradient through a narrowing is proportional to the flow through the stenosis.

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Nankoweep Canyon

Looking downstream

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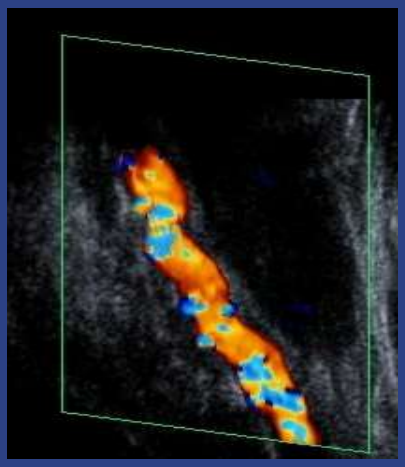
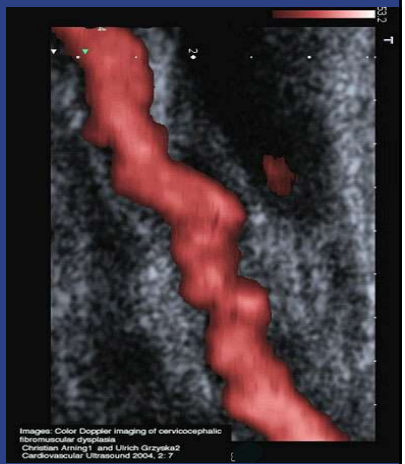
Fibromuscular Dysplasia in ICA

Image by R. Daigle





Arning C. Color Doppler imaging of cervicocephalic fibromuscular dysplasia. 2004. http://www.cardiovascularultrasound.com/content/2/1/7

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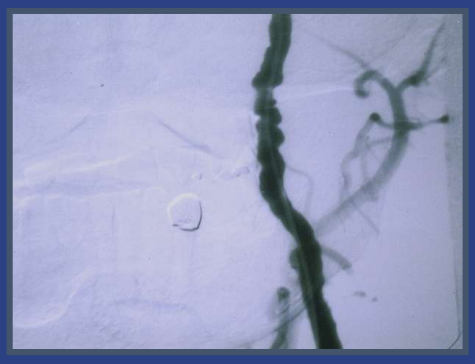
Fibromuscular Dysplasia (FMD)

- A non-atherosclerotic, non-inflammatory arterial disease of unknown causes
- Fibrous thickening of the intima, media, or adventitia
- Encroachment of lumen



Angiogram of distal ICA FMD

Image by R. Daigle

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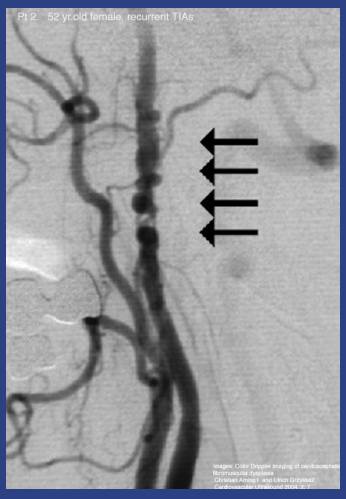
Fibromuscular Dysplasia (FMD)

- 77% present with cervical bruit
- Angio & MRA = “string of pearls”
- Color Duplex- distal ICA turbulence w/wo increase velocity



Arning C. Color Doppler imaging of cervicocephalic fibromuscular dysplasia. 2004. http://www.cardiovascularultrasound.com/content/2/1/7

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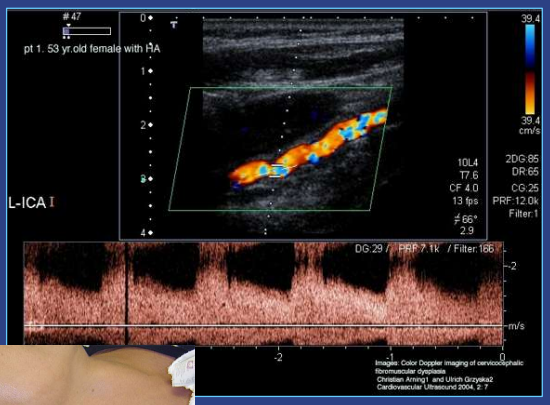
Carotid Scan Protocol- FMD

- Scan ICA “way distal” on middle-aged females (w/bruits)
- Posterior-lateral transducer position is mandatory
- FMD and Athero disease usually don’t co-exist



Arning C. Color Doppler imaging of cervicocephalic fibromuscular dysplasia. 2004. http://www.cardiovascularultrasound.com/content/2/1/7

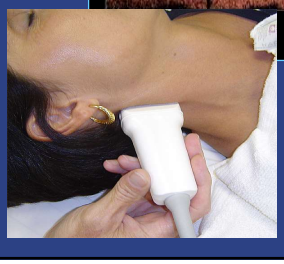


Image by R. Daigle

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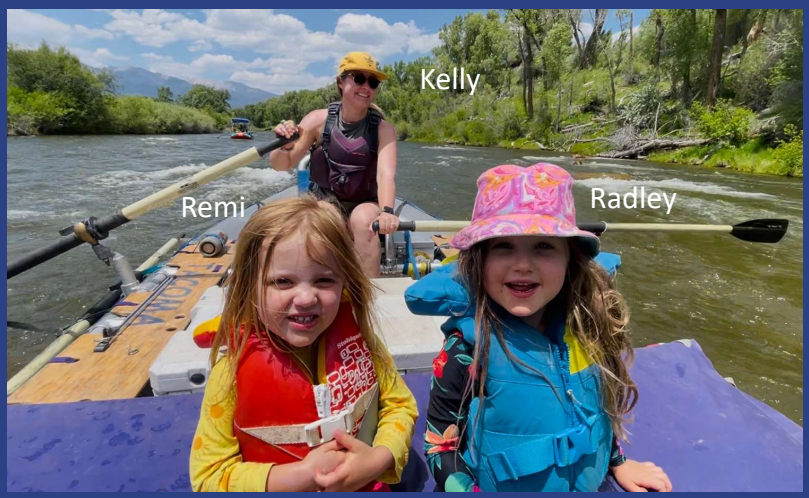
Training Camp for Future Grand Canyon Oarsmen



Images by R. Daigle

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In Summary

Understanding flow patterns and how they relate to vascular pathology is an essential skill in becoming a good vascular "detective"