HARVARD MEDICAL SCHOOL
TEACHING HOSPITAL

Carotid Duplex Ultrasonography

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Carotid Duplex Ultrasonography

- Normal carotid anatomy
- Standard ultrasonographic scanning protocol
- Grayscale/color Doppler/spectral Doppler imaging appearances
- Proper assessment of carotid stenosis
- Plaque morphology characterization
- Waveform and velocity changes
- Special carotid waveforms in the presence of cardiac disease
- Non-atherosclerotic findings on carotid Duplex
- Carotid Duplex Summary

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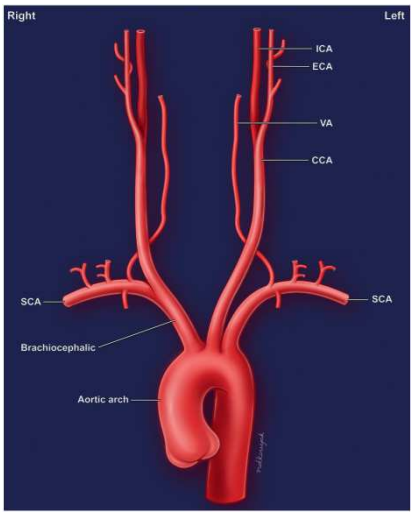
Carotid Artery Anatomy

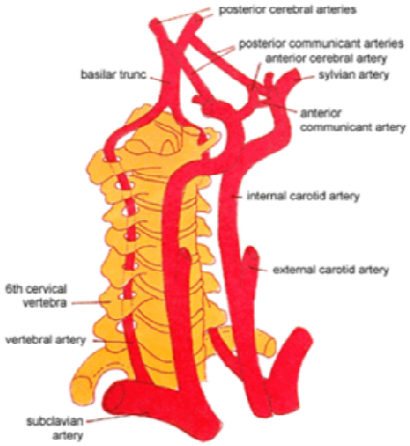
- The left common carotid artery (CCA) normally arises directly from the aortic arch.
- The right subclavian artery and the right CCA both originate from a common innominate or brachiocephalic artery.
- Near the junction of the middle and distal third of the neck, the CCA vessel dilates into the common carotid bulb. From the bulb area arises the two major carotid artery branches, the internal carotid artery (ICA) and the external carotid artery (ECA)



Scan Protocol

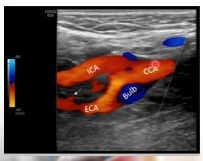
Completed exam includes:

- Common carotid artery
- Carotid bifurcation
- Internal carotid artery
- External carotid artery
- Vertebral artery
- Subclavian artery



Extra-cranial Carotid

The ECA has branches
Used to distinguish it from ICA



Fibromuscular dysplasia seen
Tortuous, kicks, coils, difficult angels, elevated velocities

Disease may extend to this area

Disease most likely to develop

1 cm

The slow/diastolic flow reversal in the bulb

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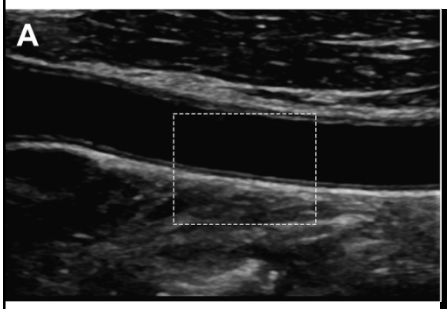
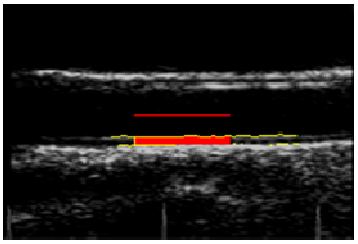
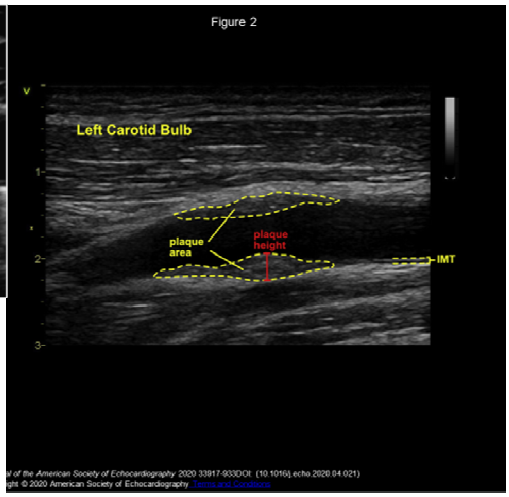
Grayscale Imaging







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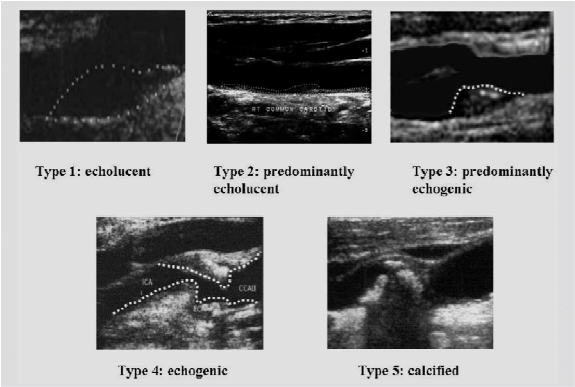
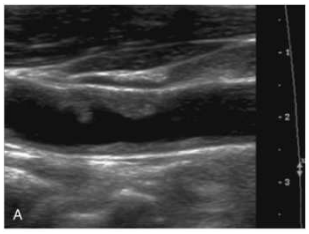
Carotid Plaque



Echogenicity

Texture

Heterogeneous plaque



Homogenous plaque

Sirico, Giusy & Spadera, Lucrezia & Laurentis, Mario & Brevetti, Gregorio. (2009). Carotid artery disease and stroke in patients with peripheral arterial disease. The role of inflammation.

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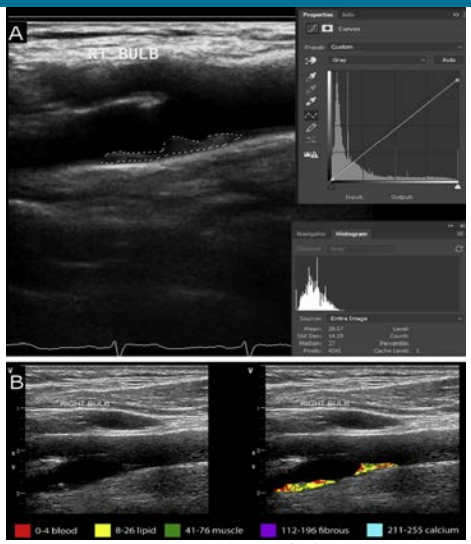
Carotid Plaque

- Increased carotid plaque echogenicity from fibrous and calcium-like tissues correlated with increased cardiovascular disease.
- Machine learning techniques allows Plaque composition analysis by grayscale median GSM and pixel distribution analysis (PDA).
- Further research will define the relationship between ultrasound gray scale values and the atherosclerotic process, investigate the emerging role of gray scale median analysis to identify plaque vulnerability and inform cardiovascular risk stratification.



Journal of the American Society of Echocardiography 2020 33917-933DOI: (10.1016/j.echo.2020.04.021)

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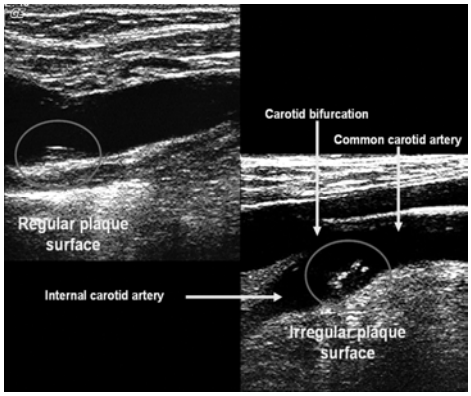
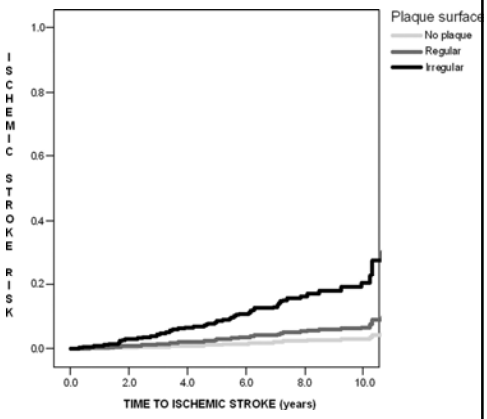
Carotid Plaque





Surface

Shyam Prabhakaran. Stroke. Carotid Plaque Surface Irregularity Predicts Ischemic Stroke, Volume: 37, Issue: 11, Pages: 2696-2701, DOI: (10.1161/01.STR.0000244780.82190.a4)

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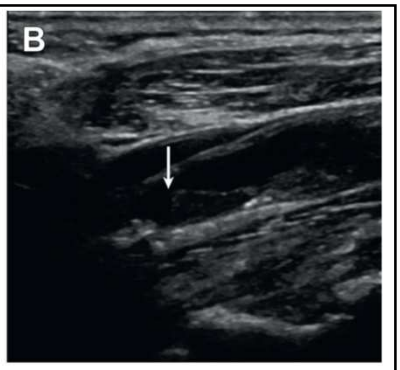
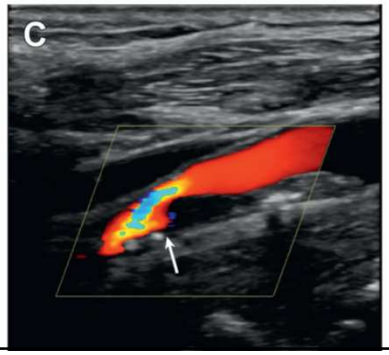


Shallow ulcer
appearing as a focal depression or defect on the surface of a plaque

Plaque ulceration

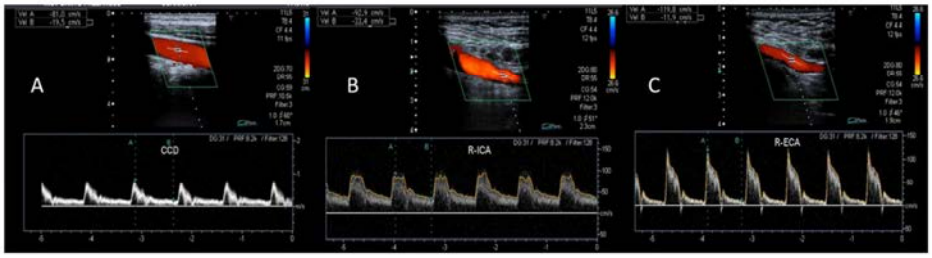
the main foci of cerebral micro emboli



Deep ulcer
appearing as an anechoic cleft (arrow) extending from within the plaque to the lumen of the vessel without a separating border of echogenicity

turbulent color flow within the anechoic defect (arrow), assisting in the detection of this lesion

Normal Carotid Duplex Waveform



- Mixed waveform appearance of the low-resistance ICA and the high-resistance ECA.
- Sharp systolic upstroke with forward antegrade flow throughout the cardiac cycle without spectral broadening

- Sharp upstroke: Increase velocity at start of systole
- Decrease velocity at the end of systole
- Antegrade Diastolic Flow throughout the cardiac cycle
- Spectrum broadening is seen
- Low resistance distal cerebral flow

- Sharp upstroke: Increase velocity at start of systole
- Rapid return to baseline with reversal: increased peripheral resistance
- Minimal Diastolic Flow
- Higher resistance than cerebral flow

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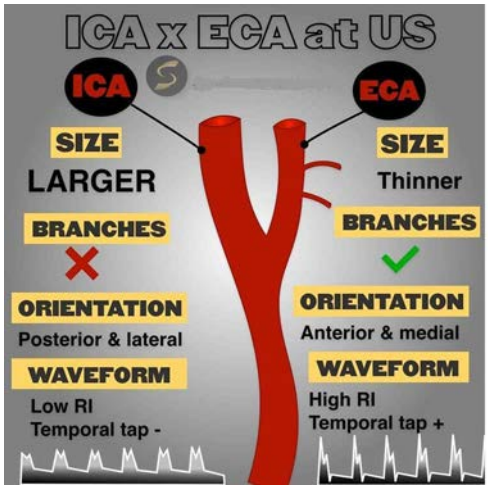
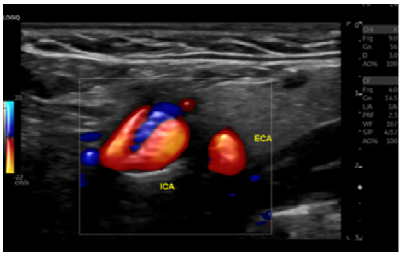
ICA Versus ECA





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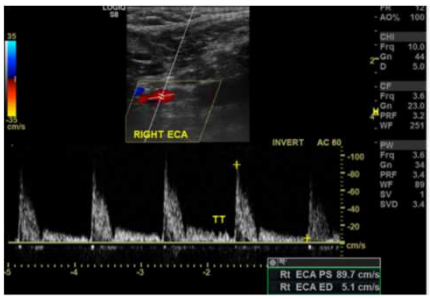
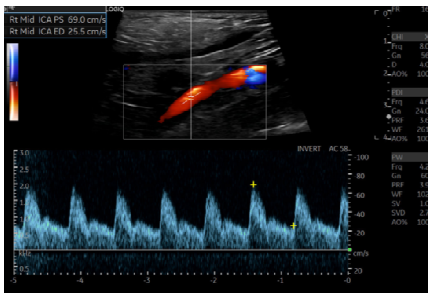
ICA Versus ECA

High Resistance ECA



Sharp upstroke that return to baseline
Minimal Diastolic Flow that reaches zero

Low Resistance ICA



Sharp upstroke that does not return to baseline , Antegrade diastolic Flow that does not reach zero

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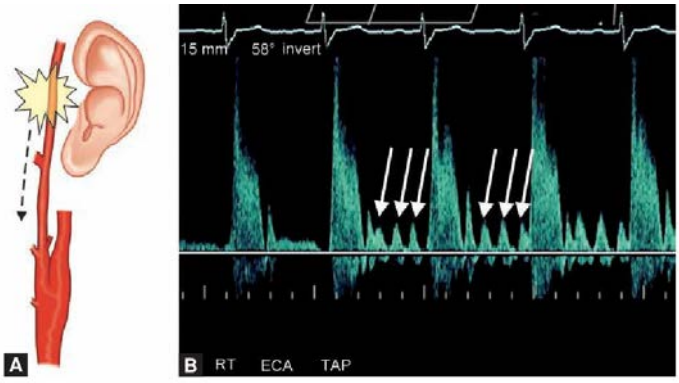
Temporal Tap ECA



: The temporal tap. The temporal tap maneuver helps to identify the external carotid artery. Rapi

- The pulsations produced by tapping the temporal artery transmit into ECA, be visualized on the spectral waveform, best seen in the diastolic component
- Identify the artery and distinguish it from the ICA
- Strong or aggressive tapping can also affect the ICA

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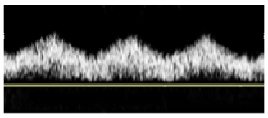
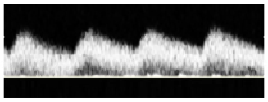
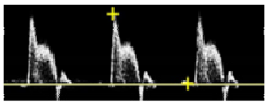
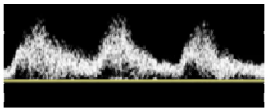
Abnormal Carotid Duplex Waveform

Pathophysiologic state and explanation	Waveform figure
Common Carotid Artery (CCA) Distal to Innominate Artery Stenosis (Right Side) Prolonged upstroke decreased peak systolic velocities, and a dampened peak are all typical features produced by a proximal obstructive lesion. There is forward flow throughout the cardiac cycle. Some spectral broadening is present, but the relatively clear (black) "window" under the systolic portion of the waveform suggests minimal turbulence, consistent with the relatively large distance between the innominate artery stenosis and the mid CCA.	
Common Carotid Artery Distal to Proximal CCA Stenosis The CCA waveform demonstrates prolonged upstroke, decreased peak systolic velocities, and a dampened peak. There is forward flow throughout the cardiac cycle and spectral broadening indicates turbulence from the more proximal CCA lesion.	
Common Carotid Artery With Ipsilateral Internal Carotid Artery Occlusion The CCA waveform demonstrates an atypical high-resistive pattern with a small reverse flow phase in late systole and absent diastolic flow. In the setting of an ipsilateral ICA occlusion, the CCA waveform resembles that of the ECA. Rapid upstroke indicates normal inflow.	
Internal Carotid Artery Distal to Common Carotid Artery Stenosis ICA waveform shows a prolonged upstroke and spectral broadening. There is forward flow throughout the cardiac cycle and relatively high diastolic flow, characteristic of an artery perfusing a low resistive vascular bed.	

Kim ES, Sharma AM, Scissons R, et al. Interpretation of peripheral arterial and venous Doppler waveforms: A consensus statement from the Society for Vascular Medicine and Society for Vascular Ultrasound. Vascular Medicine. 2020;25(5):484-506.

Stenosis Diagnostic Criteria

A. *Interpreting ICA Stenosis Severity*

MGH current criteria

Category	% Diameter stenosis	Peak systolic velocity (cm/sec)	Spectral broadening	End diastolic velocity (cm/sec)	ICA/CCA PSV ratio
Normal	0–19	<105	Absent	N/A	N/A
Mild	20–49	≥105–<150	Present	N/A	N/A
Moderate	50–69	≥150–<250	Present	N/A	≥2.0–<4.0
Severe	70–89	≥250	Present	<135	≥4.0[a]
Very severe	90–99	≥250	Present	≥135	≥5.0
Functionally occluded	100	N/A	Pre-occlusive Wall "thump"	N/A	N/A

[a]If ICA/CCA peak systolic ratio ≥4.0, this suggests ≥70% stenosis

B. *Common Carotid Artery Stenosis*

1. An increase in peak systolic velocity of ≥100% (doubling) equates to ≥50% stenosis.

2. An increase in peak systolic velocity of ≥300% (tripling) equates to ≥75% stenosis.

C. *External Carotid Artery Stenosis*

1. A peak systolic velocity of ≥200 cm/s equates to≥50% stenosis.

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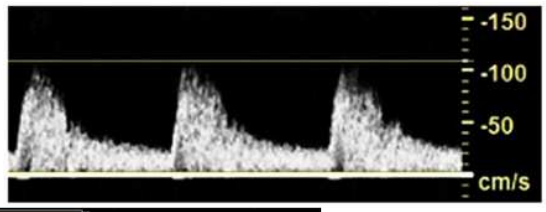
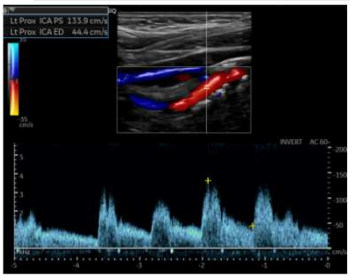
ICA stenosis

- Peak velocities in this proximal ICA are below the commonly used threshold of 150 cm/sec for a ⩾ 50% ICA stenosis.
- Spectral broadening throughout the cardiac cycle represents turbulent flow produced by the stenotic lesion.





20-49% stenosis

ICA PSV 105-150 cm/s

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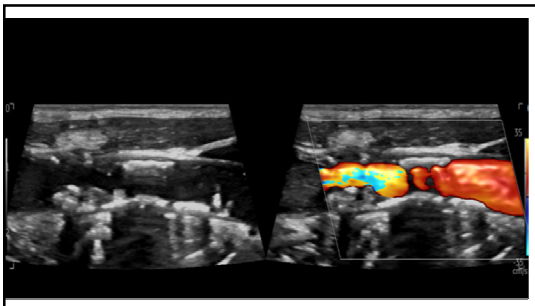
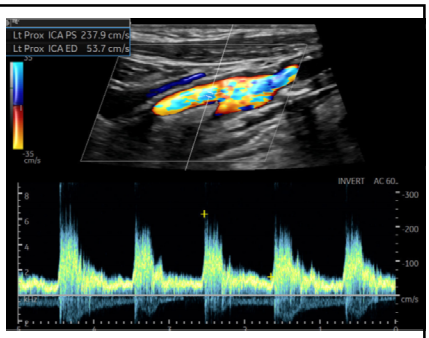
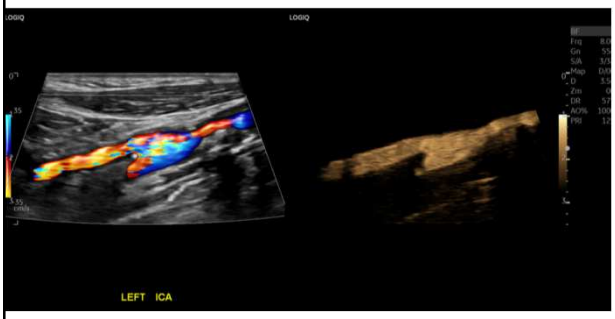
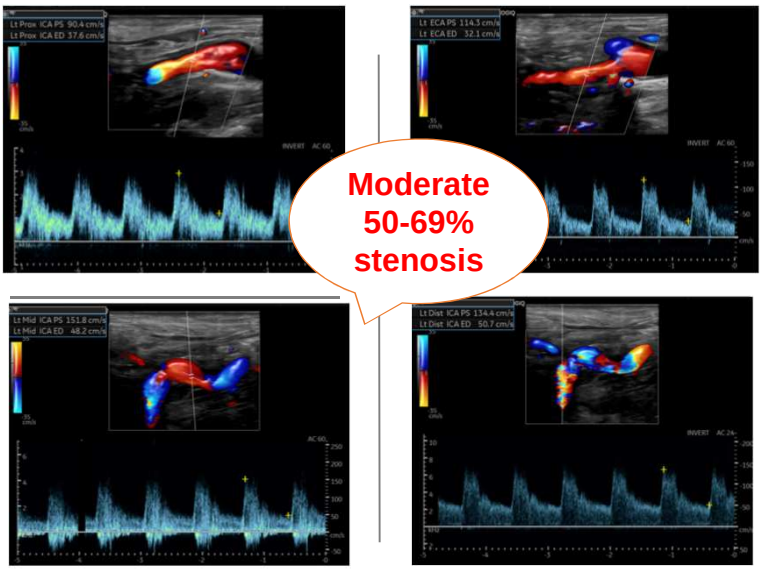






Moderate 50-69% stenosis

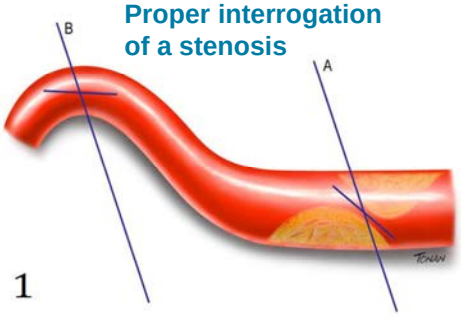
ICA PSV 150-250 cm/s

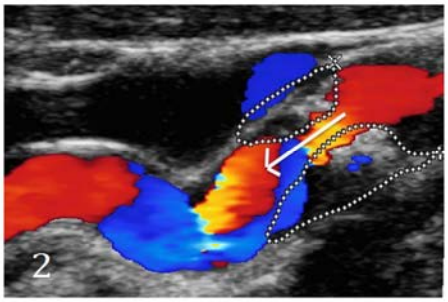


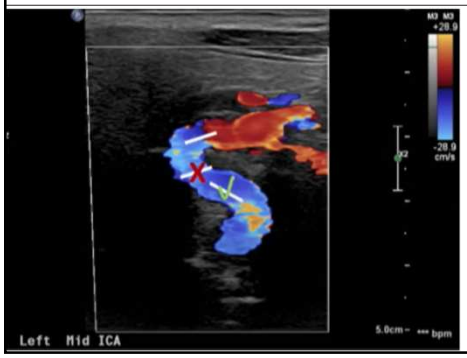
ICA PSV 150-250 cm/s

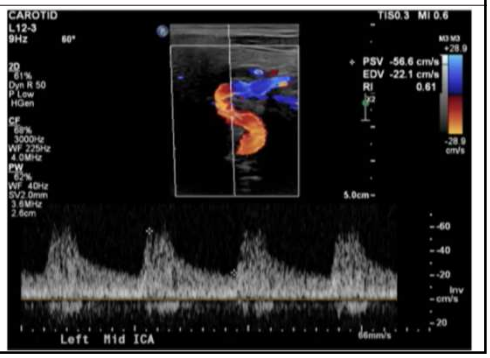
these velocities may be elevated due to the tortuosity of the vessel

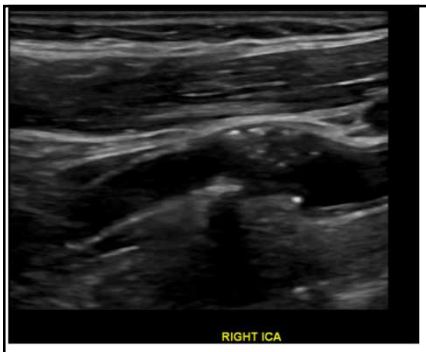
Proper interrogation of a stenosis

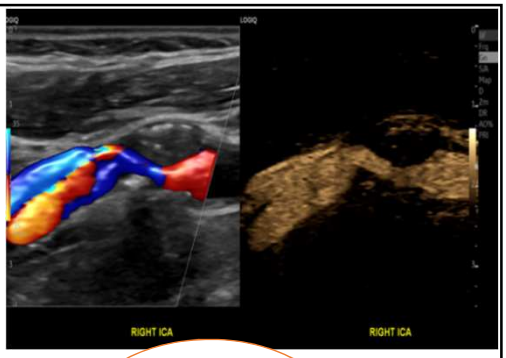


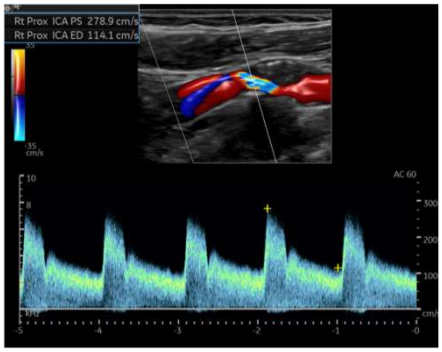










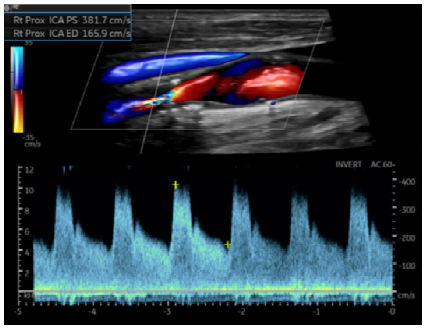


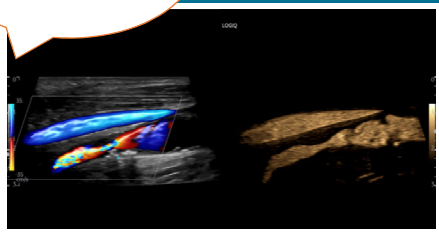
ICA 70-89% stenosis

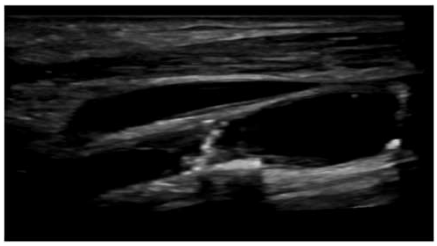
ICA PSV >250 cm/s
EDV<135 cm/s
ICA/CCA >=4.0

ICA stenosis

90-99% stenosis







ICA PSV >250 cm/s
EDV>135 cm/s
ICA/CCA >=5.0

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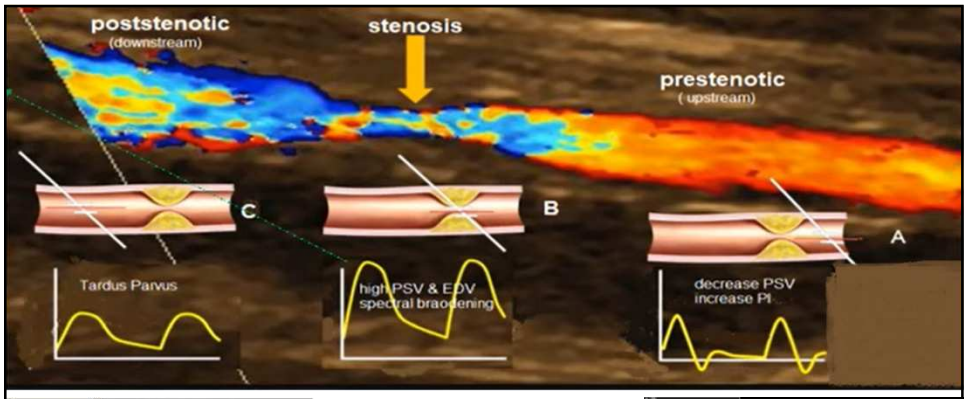
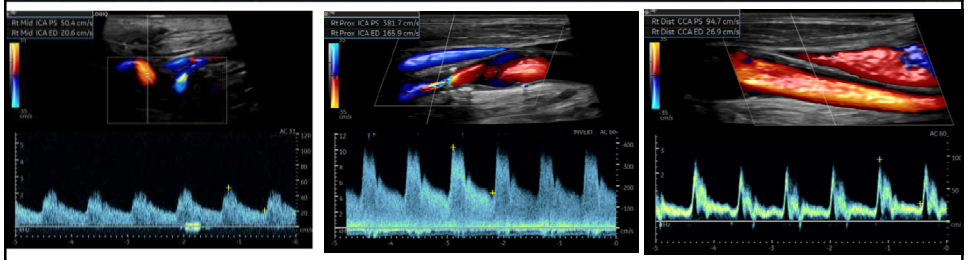




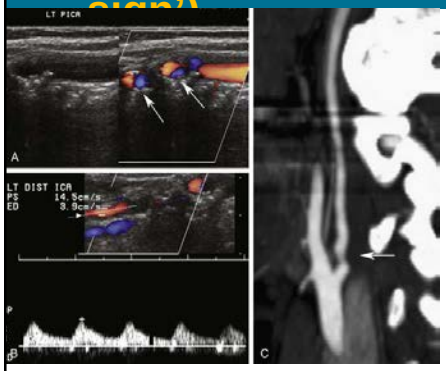
Post stenotic slow systolic rise and dampening of flow velocities

Turbulent flow with spectral burdening, elevated PSV,EDV

high-resistive pattern with a small reverse flow phase in late systole

Vascular Ultrasound Statement • Arq. Bras. Cardiol. 112 (6) • June 2019

ICA near occlusion ('string sign')



- A focal high-velocity jet may not be present
- The waveform often demonstrates decreased velocities.
- Distinguishing carotid occlusion from high-grade carotid stenosis is critical and can be a challenging. Low flow in a near-total occlusion may be difficult to detect with preset Doppler parameters and requires optimization of color, power, and pulsed Doppler settings.

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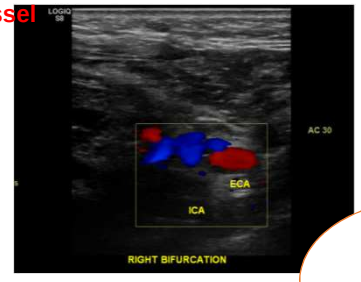
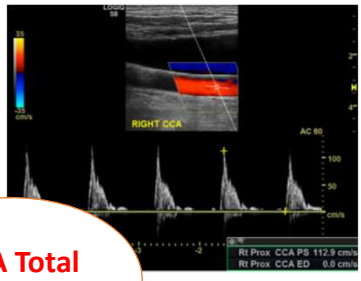
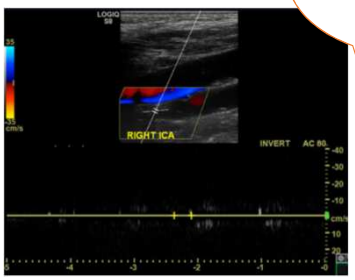
Cross-sectional image can be very helpful in determining patency of a vessel

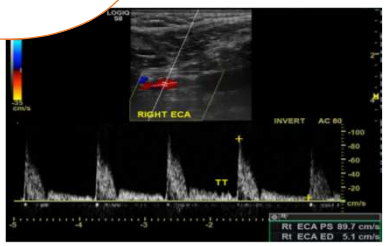
ICA occlusion





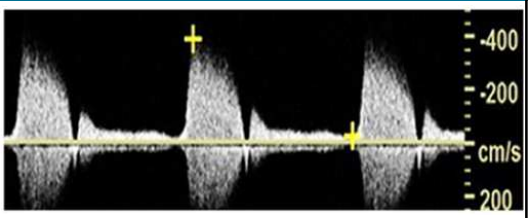
RICA Total Occluded

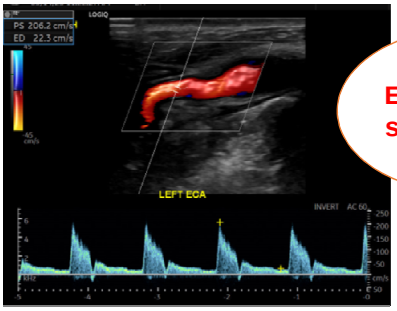




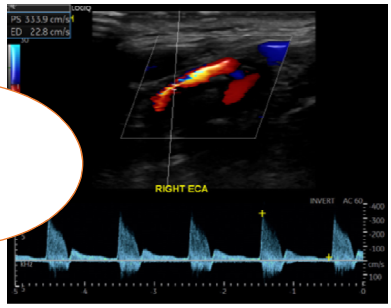
ECA stenosis

- Increased peak velocities and extensive spectral broadening indicate a stenosis in the proximal ECA.
- A reverse flow phase in late systole and a multiphasic flow pattern, are characteristic of the ECA.





ECA >50% stenosis



ECA PSV >200 cm/s

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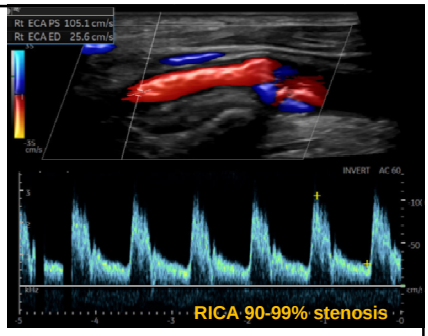
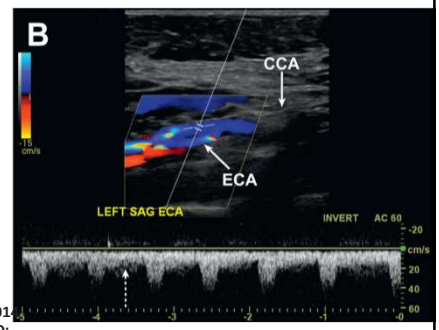
Internalization of the ECA

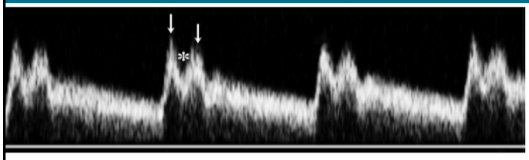
(A) High-grade stenosis of the ipsilateral ICA, causing a change in the ECA waveform to a low-resistance pattern, with increased diastolic flow.
(B) Occlusion of the ipsilateral CCA, the ECA shows reversed flow, with a low-resistance waveform pattern, characterized by increased diastolic flow, because the ECA now provides the blood supply for the ipsilateral ICA.



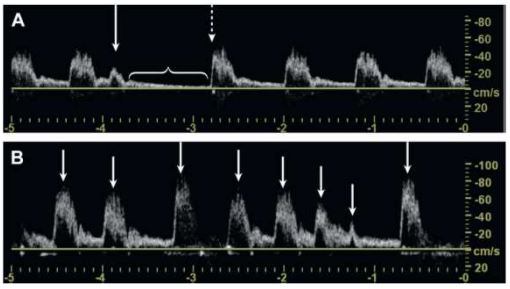


Kaproth-Joslin KA, Bhatt S, Scoutt LM, Rubens DJ. The essentials of extracranial carotid ultrasonographic imaging. Radiol Clin North Am. 2014 Nov;52(6):1325-42. doi: 10.1016/j.rcl.2014.07.010. Epub 2014 Sep 4. PMID: 25444109

Cardiac disease on carotid artery waveforms



Pulsus bisferiens waveform secondary to aortic regurgitation showing 2 sharp systolic peaks with an interposed mid systolic dip



Cardiac arrhythmias.
(A) Premature ventricular contraction causing an artificially low PSV followed by a compensatory pause and a subsequently high PSV
(B) Atrial fibrillation causing irregular waveform morphology with varying PSV amplitudes

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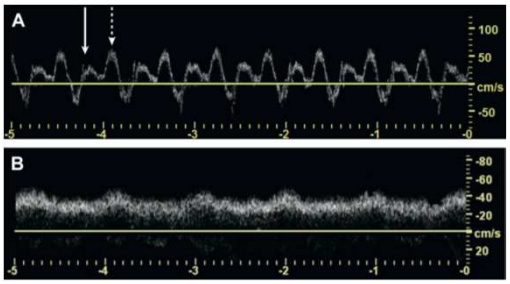
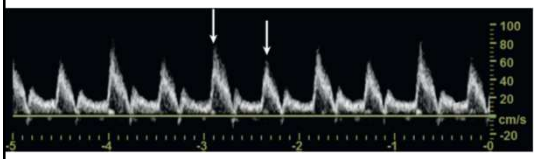
Cardiac disease on carotid artery waveforms



Cardiac assist devices.
(A) IABP creating a characteristic waveform with 2 peaks followed by flow reversal at end diastole
(B) LVAD creating a monophasic antegrade waveform pattern with a slow systolic upstroke and a rounded systolic peak, mimicking a tardus parvus waveform.



Pulsus alterans waveform secondary to left ventricular systolic impairment showing alternating strong and weak systolic upstrokes in the setting of a regular cardiac rhythm.

- **Cardiac arrhythmias and cardiac assistance devices are common causes of abnormal carotid waveform and changes in PSV. PSV should be calculated from the most normal appearing waveform and use of the PSV ICA/PSV CCA ratio may be more reliable than PSV alone for the evaluation of stenosis.**

Kaproth-Joslin KA, Bhatt S, Scoutt LM, Rubens DJ. The essentials of extracranial carotid ultrasonographic imaging. Radiol Clin North Am. 2014 Nov;52(6):1325-42.

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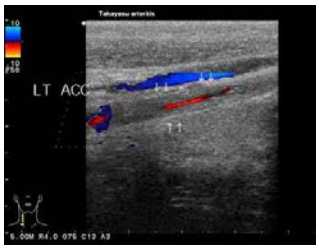
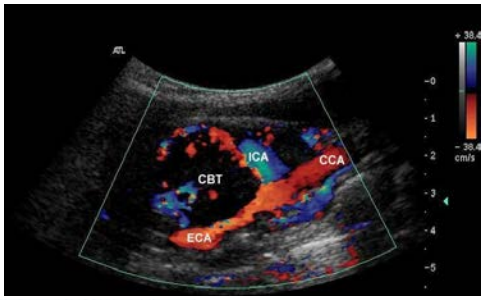
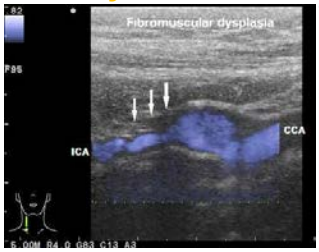
Non-atherosclerotic carotid disease



Takayasu arteritis

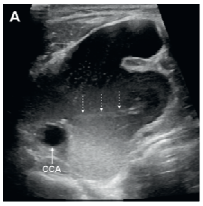


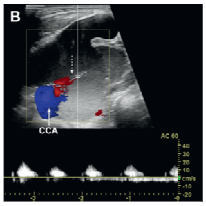
Carotid body tumor



Ffibromuscular

Hematoma





Pseudoaneurysm

Tong Y. Role of duplex ultrasound in the diagnosis and assessment of carotid body tumour: A literature review. Intractable Rare Dis Res. 2012 Aug;1(3):129-33

Arijana Lovrencic-Huzjan,Diagnosis of non-atherosclerotic carotid disease, Perspectives in Medicine,Volume 1, Issues 1–12,2012,Pages 244-249

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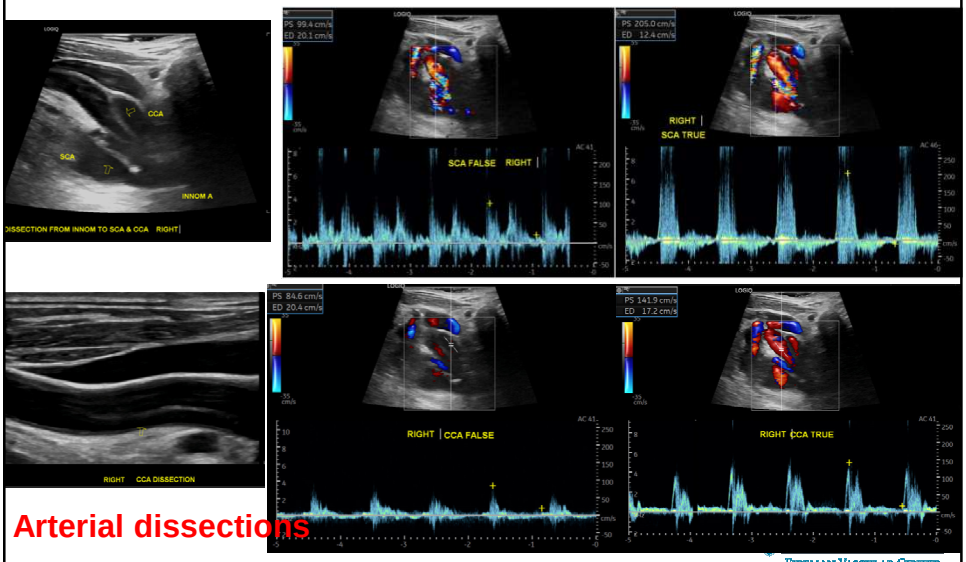
Non-atherosclerotic carotid disease



Arterial dissections

Understand the normal grayscale, color Doppler, and spectral Doppler imaging of the extracranial carotid arteries.

Assess plaque morphology characteristics with echogenicity, texture and surface.

Grade carotid artery stenosis using waveform and velocity criteria

Recognize special carotid artery waveforms in the presence of cardiac disease

Identify nonatherosclerotic findings such as Takayasu's arteritis, fibromuscular dysplasia, Carotid body tumor, Hematoma, Pseudoaneurysm and arterial dissection on carotid duplex

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