THE UNIVERSITY of TENNESSEE
HEALTH SCIENCE CENTER

Waveform Recognition

Andrei V. Alexandrov, MD
Semmes-Murphey Professor and Chairman
Department of Neurology
The University of Tennessee Health Science Center
Memphis, TN

The Journal for Vascular Ultrasound 36(2):1–10, 2012

Extra- and Intracranial Waveform Analysis Algorithm, Descriptions, Classifications, and Differential Diagnosis

Andrei V. Alexandrov, MD, RVT

"Doppler waveform never lies. It is our own inability to understand its language is the problem."
—Merrill P. Spencer, MD

Algorithm for Waveform Analysis

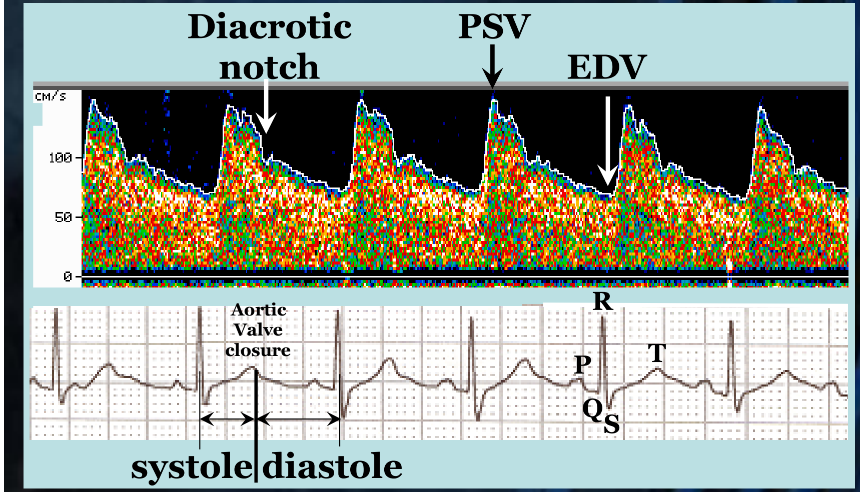
Step 1. Identify the beginning and the end of a single cardiac cycle (Figure 1, upper left insert).

Step 2. Determine the following aspects:

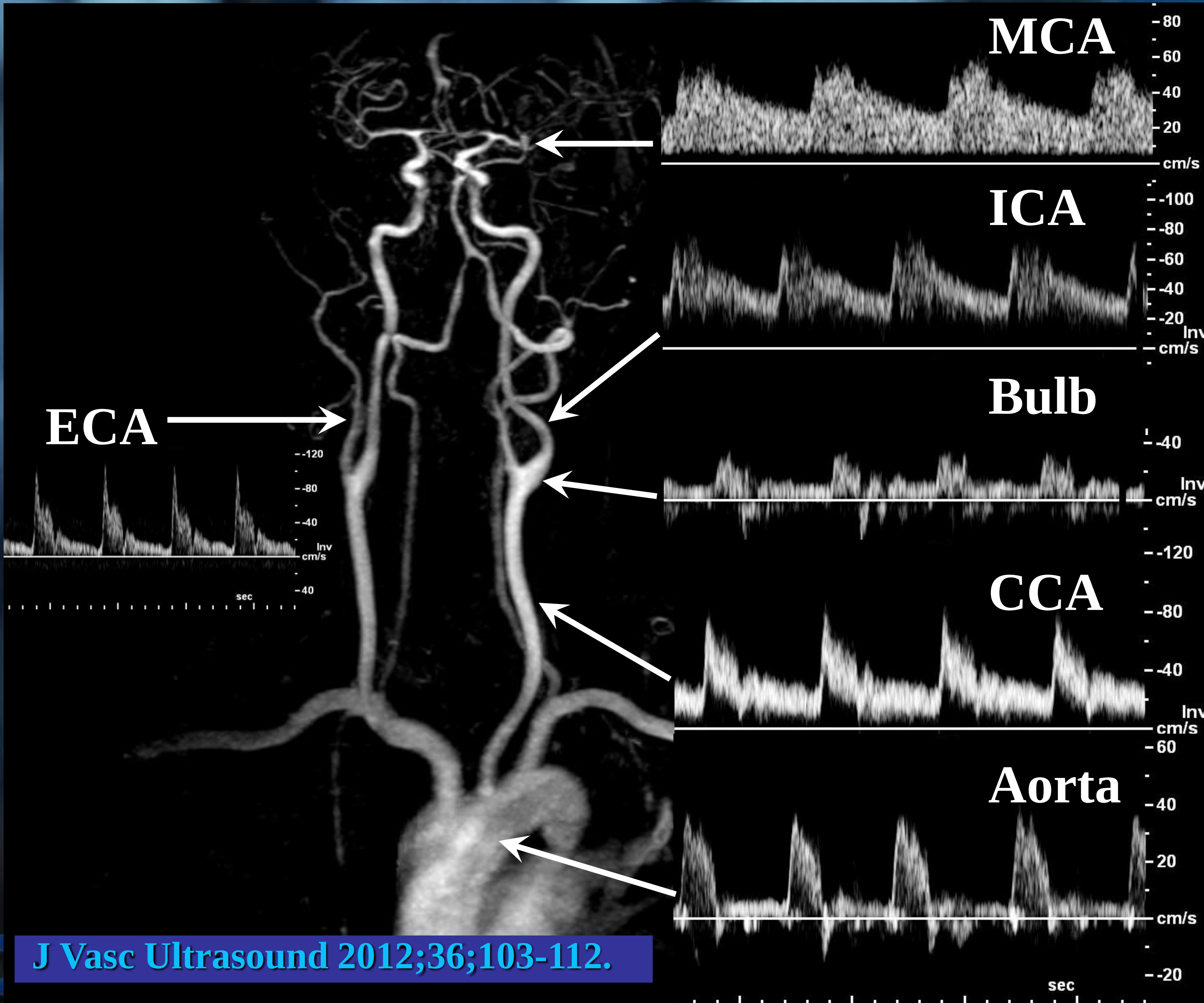
- sharpness of the systolic flow acceleration;
- the end-diastolic flow consistent with the expected resistance in the arterial system supplied by the sampled vessel;
- waveform shape transmission from the proximal to the distal part of the vessel;
- symmetry with the contra-lateral homologous segment; and
- the presence of any cardiac, systemic or focal circulatory condition that could explain the waveform.

Step 3. Synthesize the information and explain the waveform appearance as attributable to:

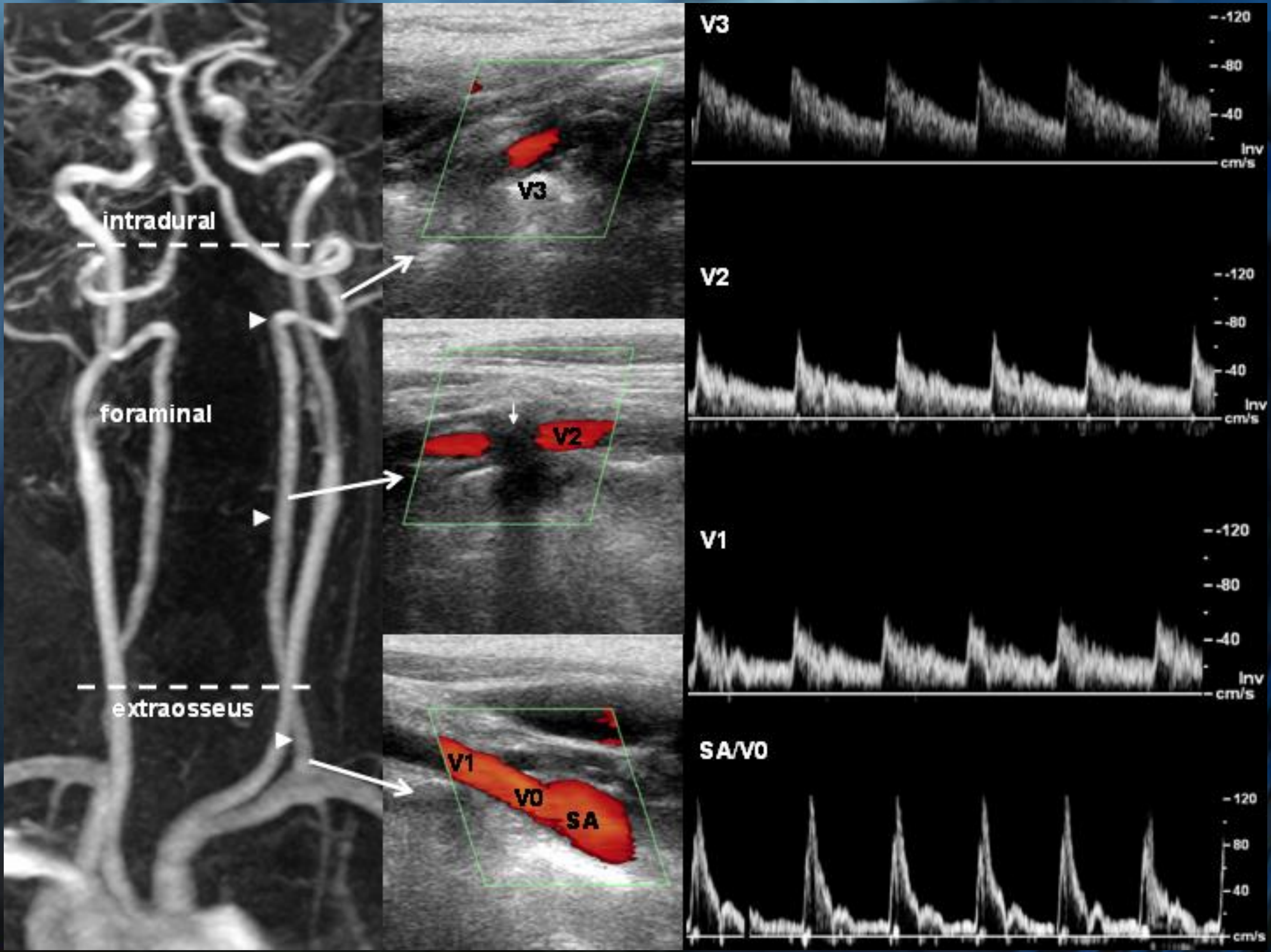
- technical error or an artifact;
- systemic hemodynamic conditions;
- the presence of a focal lesion; and
- increased, normal, or decreased intracranial resistance.



J Vasc Ultrasound 2012;36;103-112.



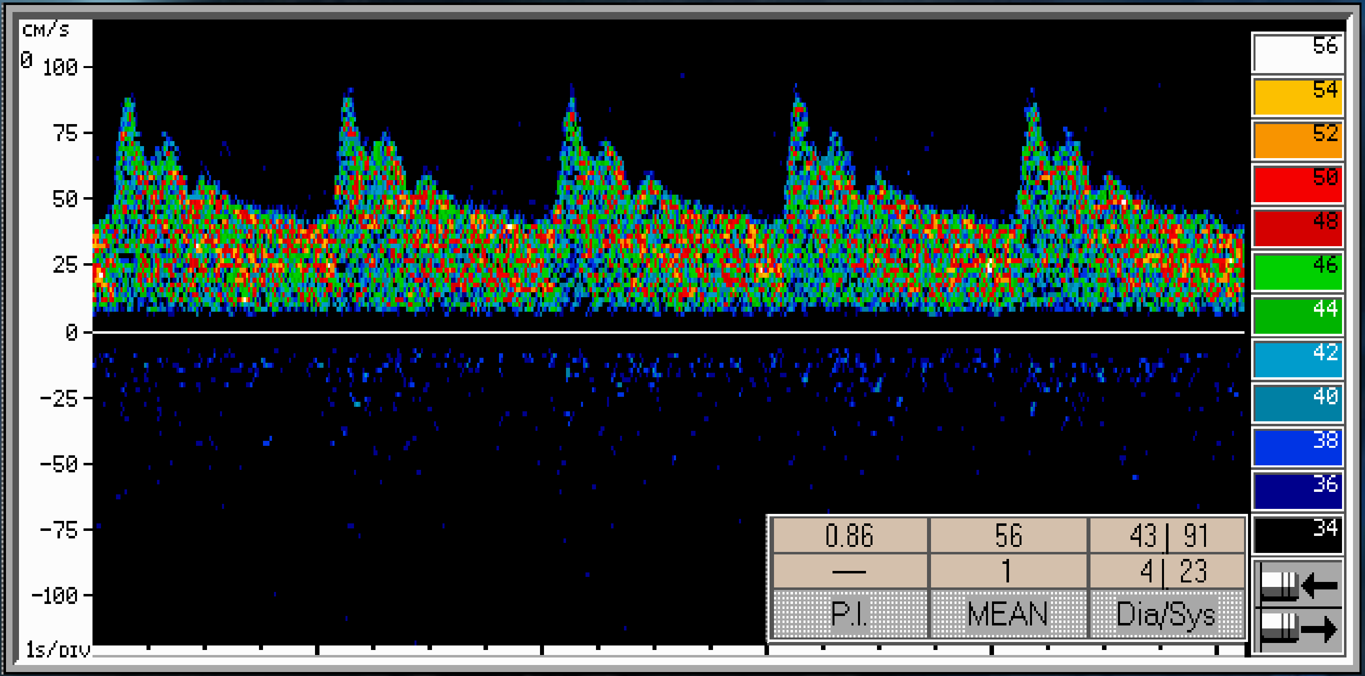
J Vasc Ultrasound 2012;36;103-112.



J Vasc Ultrasound 2012;36;103-112.

Waveform Recognition

An asymptomatic 32 year old man with arterial blood pressure 130/80.



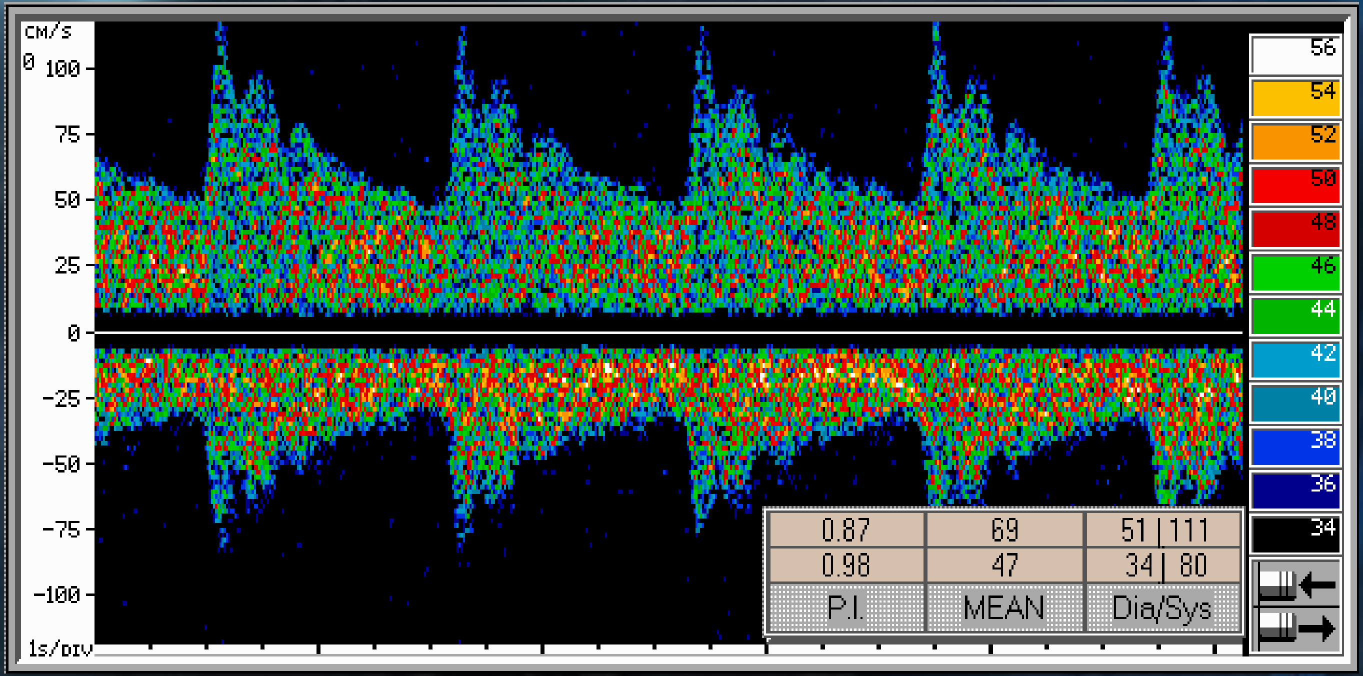
Interpretation:

this waveform shows a sharp systolic flow acceleration and stepwise deceleration with positive end-diastolic flow. The end-diastolic velocity, that is between 20% - 50% of peak systolic values, indicates a low resistance to arterial flow.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

An asymptomatic 32 year old man with arterial blood pressure 130/80.

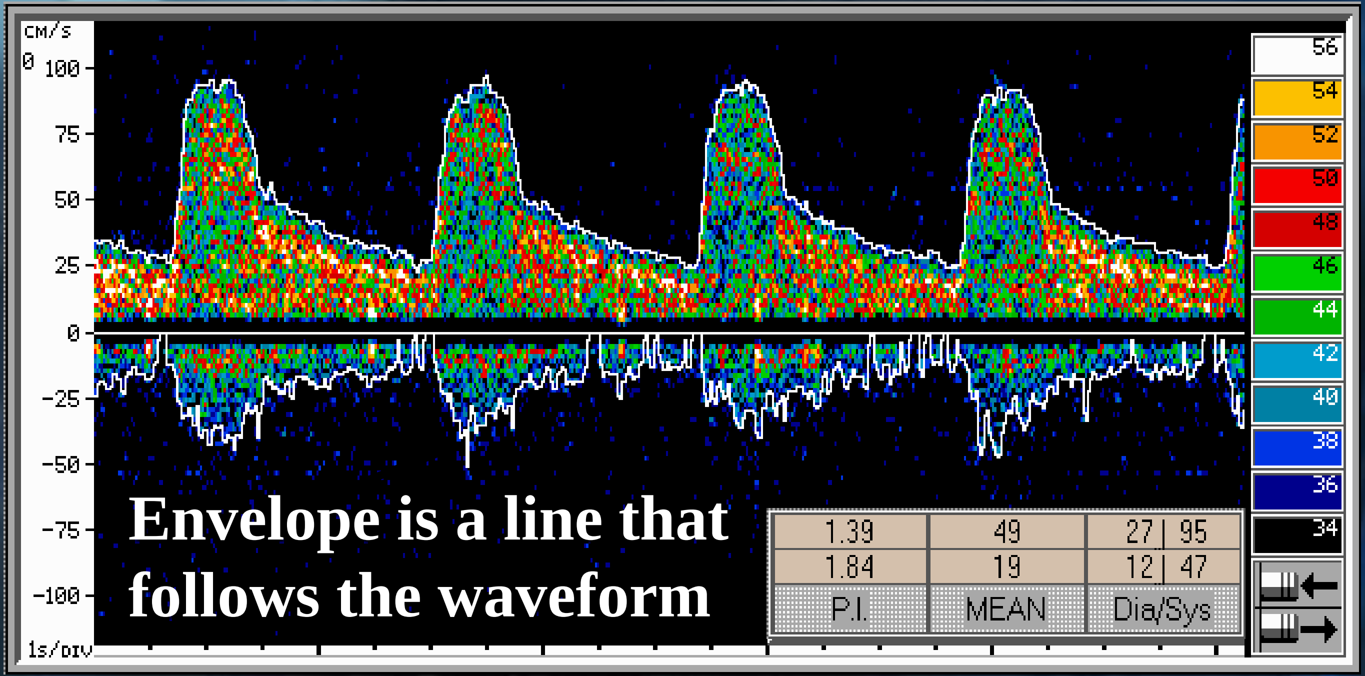


Interpretation:
this recording shows a bi-directional signal with simultaneous sharp systolic up-strokes and similar stepwise deceleration in both flow directions. Both waveforms show low resistance flow patterns.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 65 year old man with a new onset aphasia and chronic hypertension.

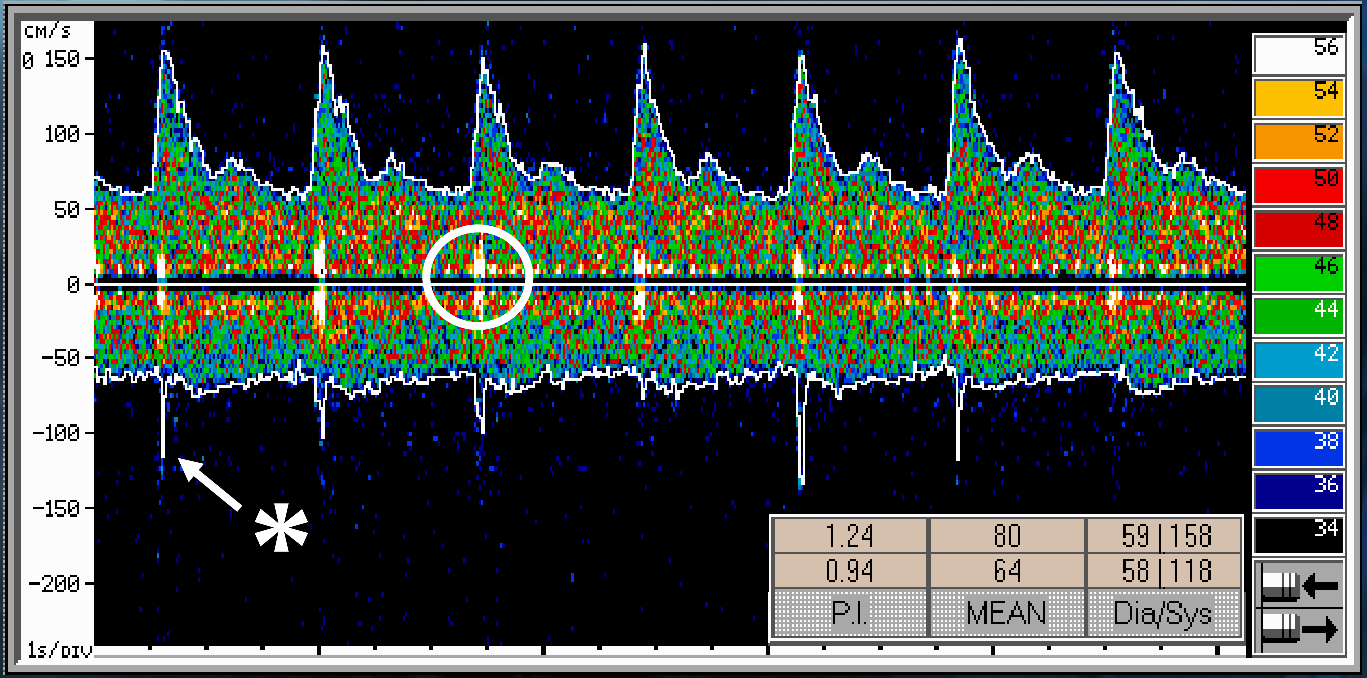


The waveform above baseline has a rapid systolic up-stroke and a rounded peak systolic complex followed by a stepwise flow deceleration. The end-diastolic velocities below 30% of peak systolic values indicate relative increase in flow resistance. Weak signal below baseline is not optimized and measurements are erroneous.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 37 year old man with closed traumatic brain injury, ICP 52 mm Hg.

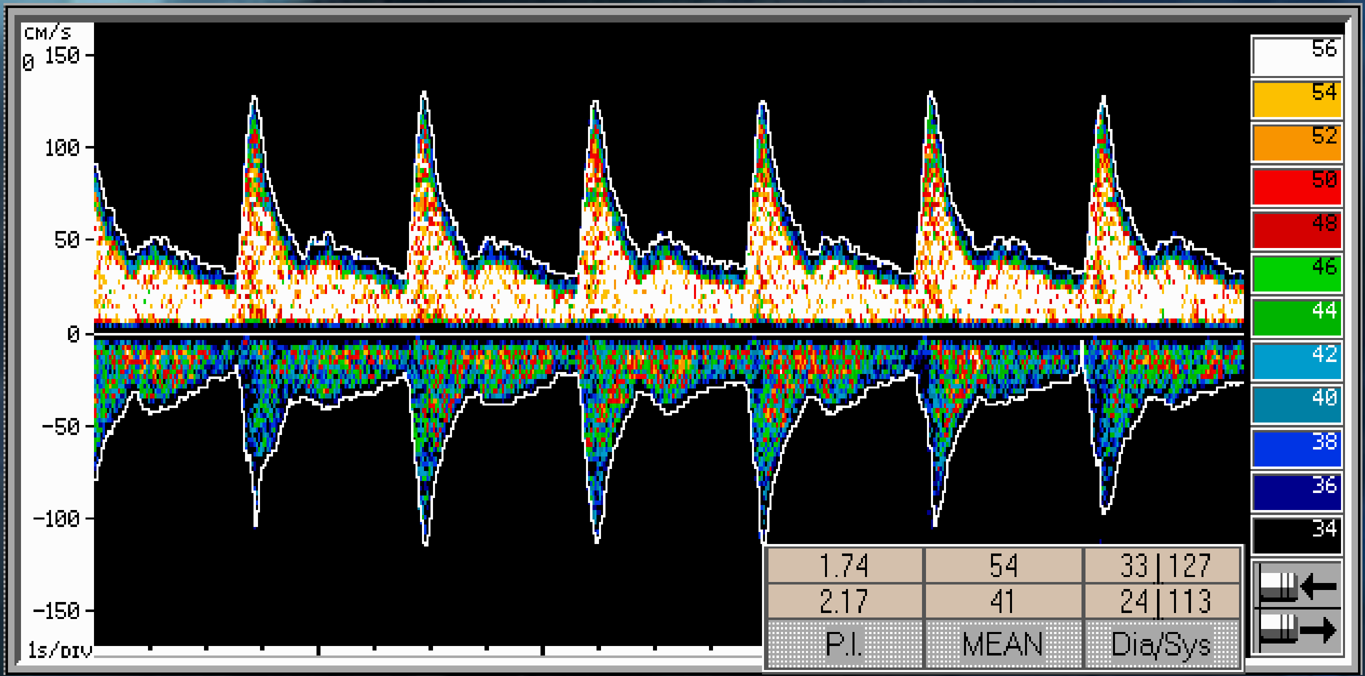


Above baseline: sharp systolic up-strokes are followed by sharp deceleration indicating an increased resistance to flow. Below baseline: a low resistance flow in a vein. A loud thump-like early systolic sound (circled) due to vessel wall motion causes envelope spikes (*) and measurement errors below baseline.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 35 year old man with subarachnoid hemorrhage (Day 2), liver failure.

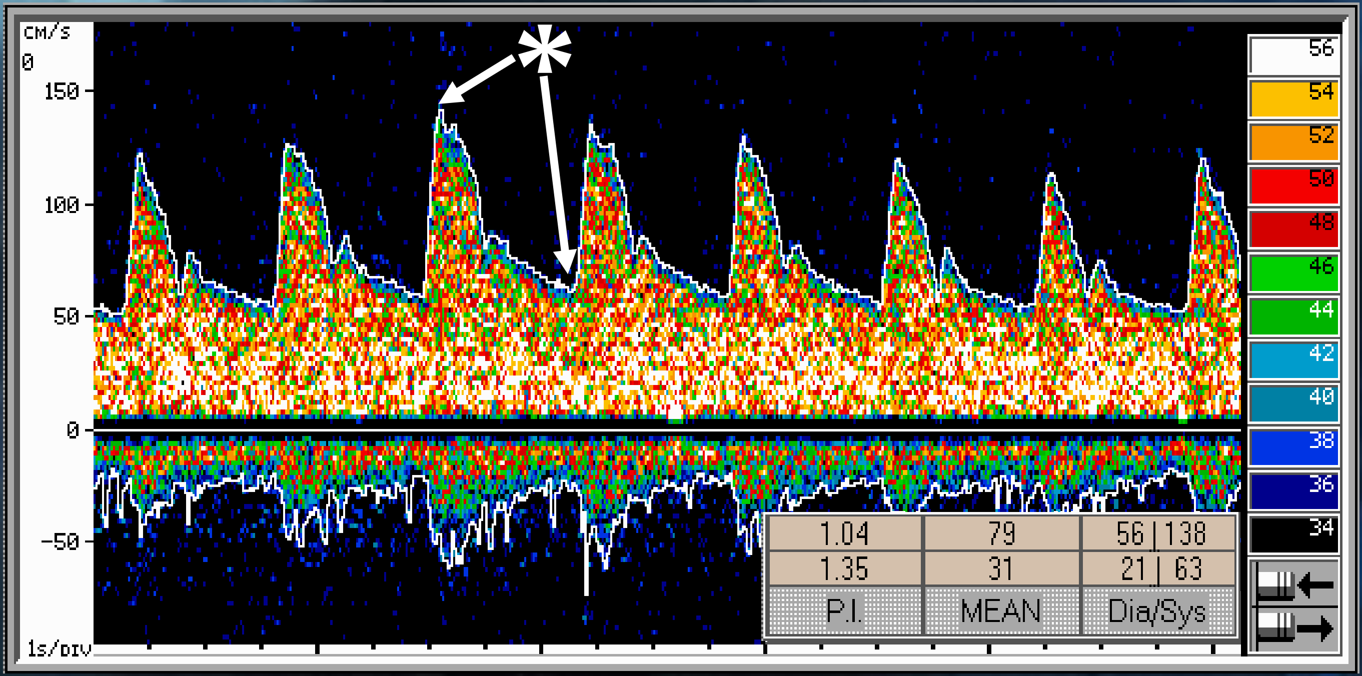


Both waveforms have sharp systolic up-strokes and an abrupt flow deceleration. These pulsatile waveforms with the end-diastolic velocities within 20% - 25% of peak systolic values indicate high resistance to arterial flow due to increased cardiac output and autoregulatory response.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 42 year old woman with closed traumatic brain injury.

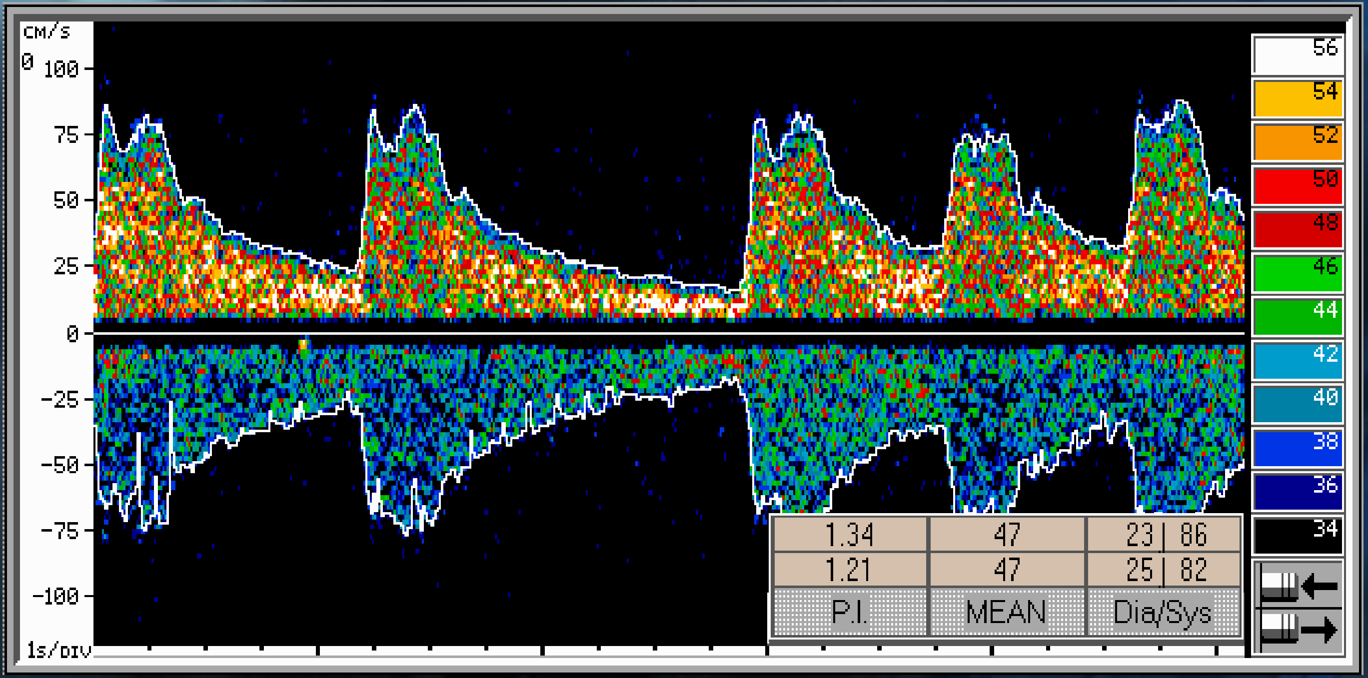


The waveforms above baseline (sharp systolic up-strokes, stepwise deceleration, low resistance) have variable velocities with regular heart rate. Velocity fluctuations can spontaneously occur every 4 cardiac cycles due to breathing. A cycle with the highest velocities (*) can be used for manual calculations.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 54 year old man with an acute small cortical stroke and LVH.

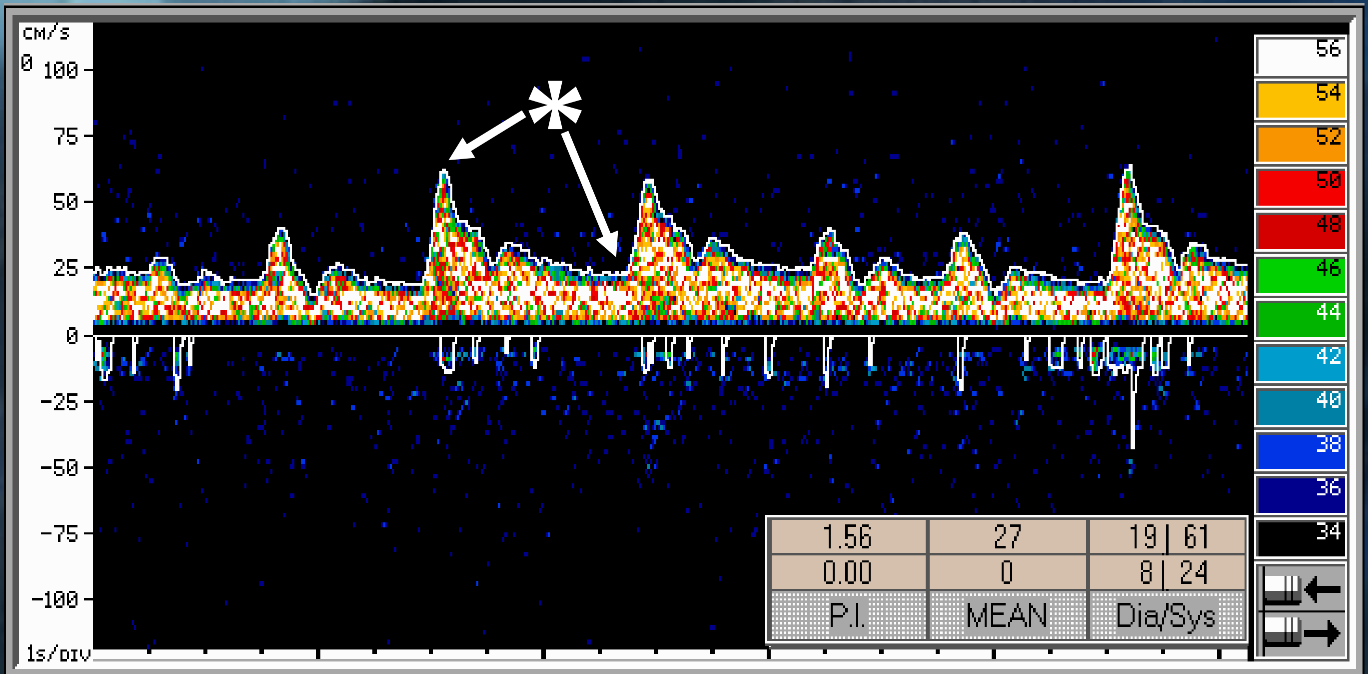


Both waveforms have sharp up-strokes, late arrival of maximum systolic velocites, and stepwise flow deceleration. The end-diastolic velocities fall below 30% of peak systoli due to irregular heart rate: this also affects estimation of flow resistance using single cardiac cycle or only 2-5 cycles-averaged values.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

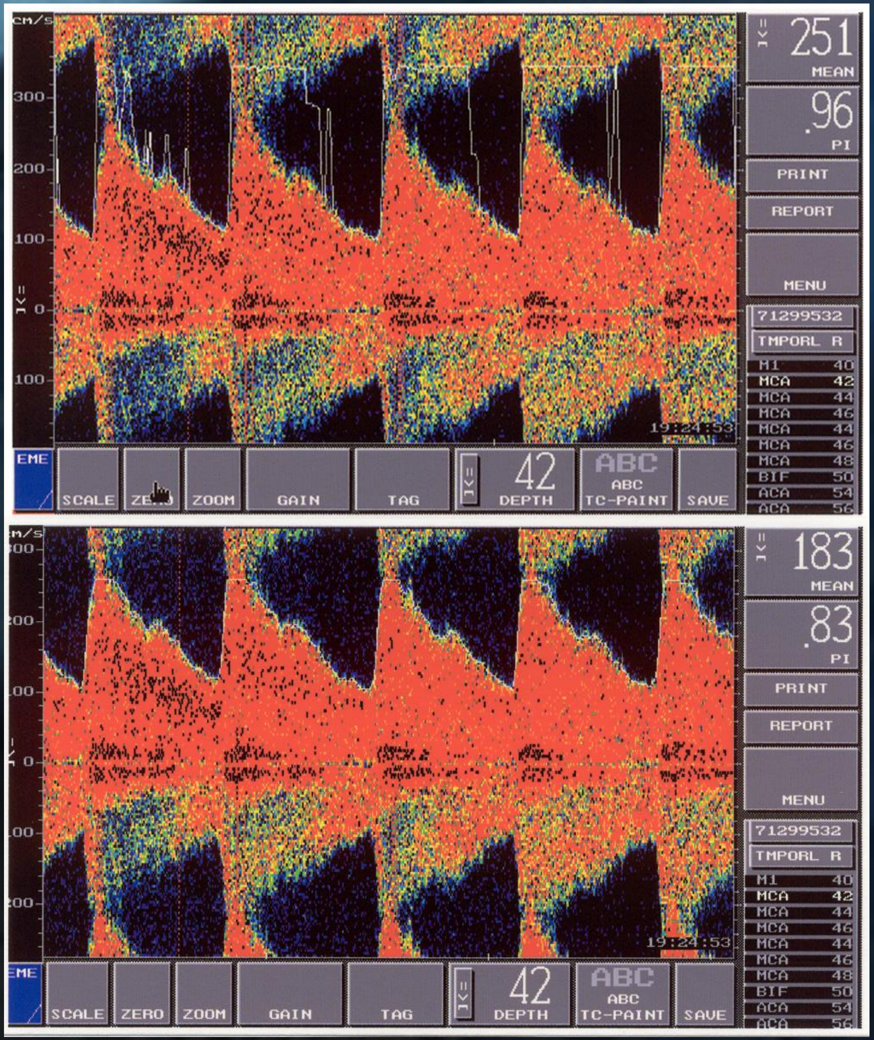
A 60 year old woman with recent TIA and atrial fibrillation.



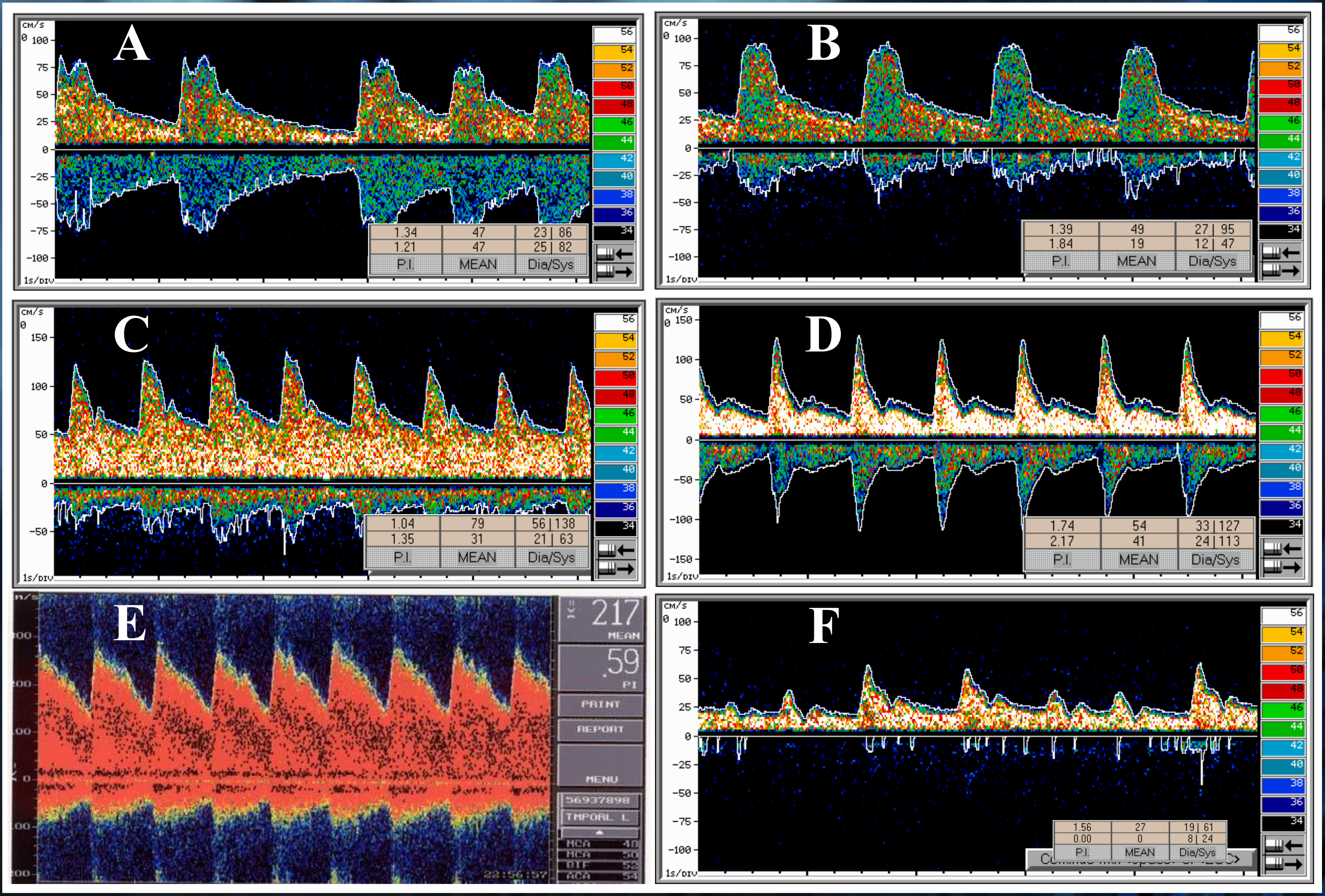
Waveforms towards the probe have irregular arrival of cardiac cycles with sharp up-strokes and variable velocities. As a practical rule, a cycle with the highest velocities (*) can be used for manual calculations. However, estimation of flow resistance and representative mean velocity is difficult since the pulse rate and cardiac output are affected.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Signal Optimization



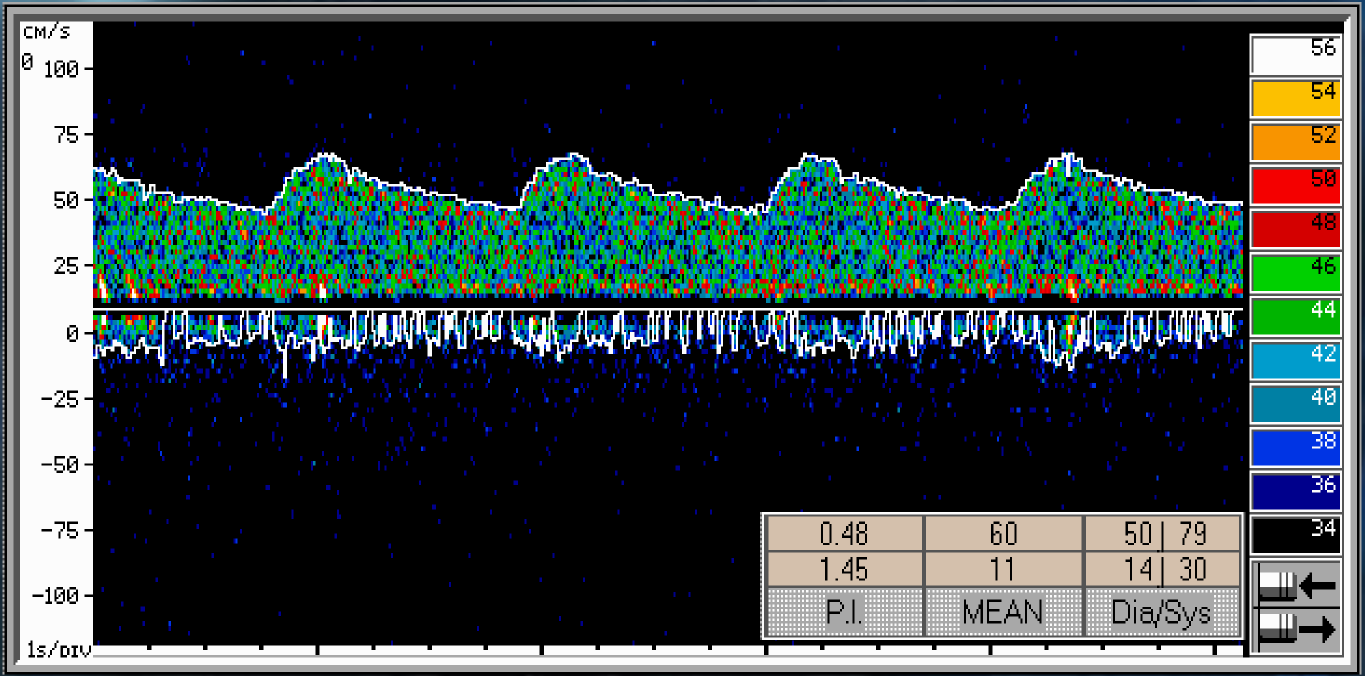
Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.



J Vasc Ultrasound 2012;36;103-112.

Waveform Recognition

A 67 year old man with resolving MCA stroke and carotid occlusion.

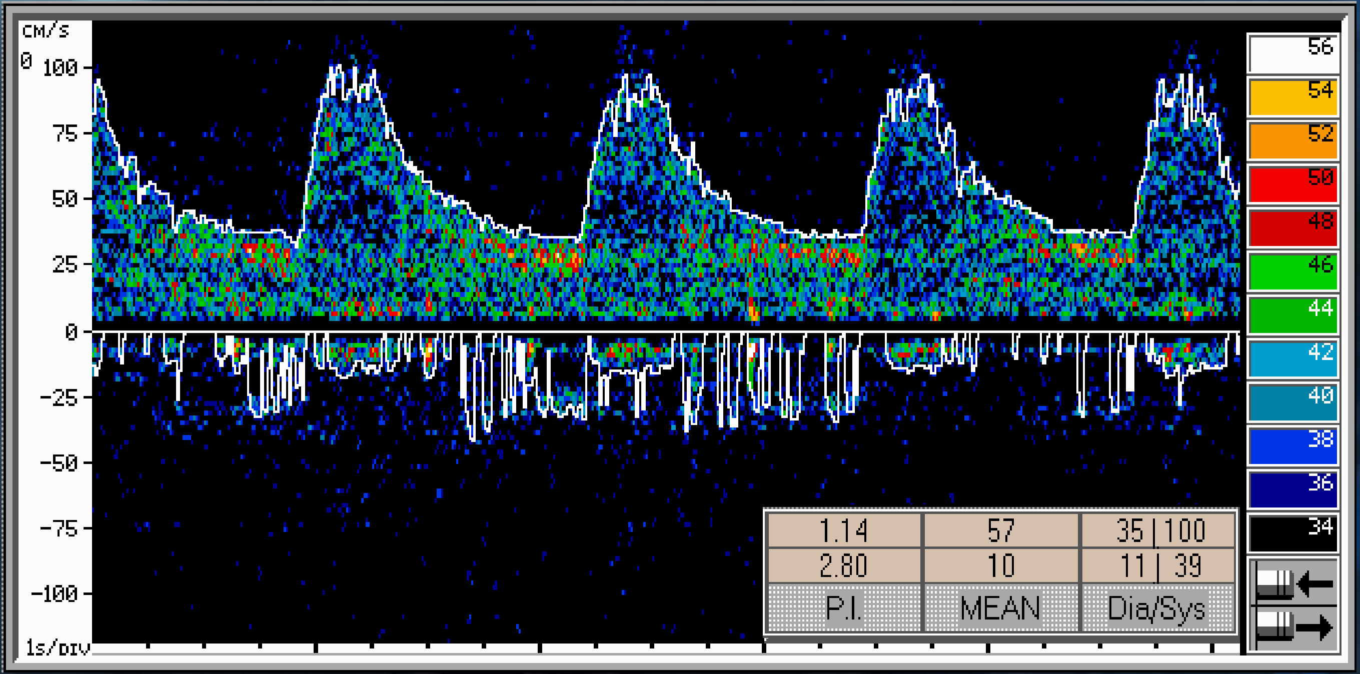


The waveform above baseline shows a delayed systolic flow acceleration, flattened systolic complex, and slow diastolic deceleration. End-diastolic velocities above 50% of peak systoli indicate very low flow resistance. In cerebrovascular studies, this waveform is called a “blunted” flow signal.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 73 year old male with MCA stroke and carotid occlusion.

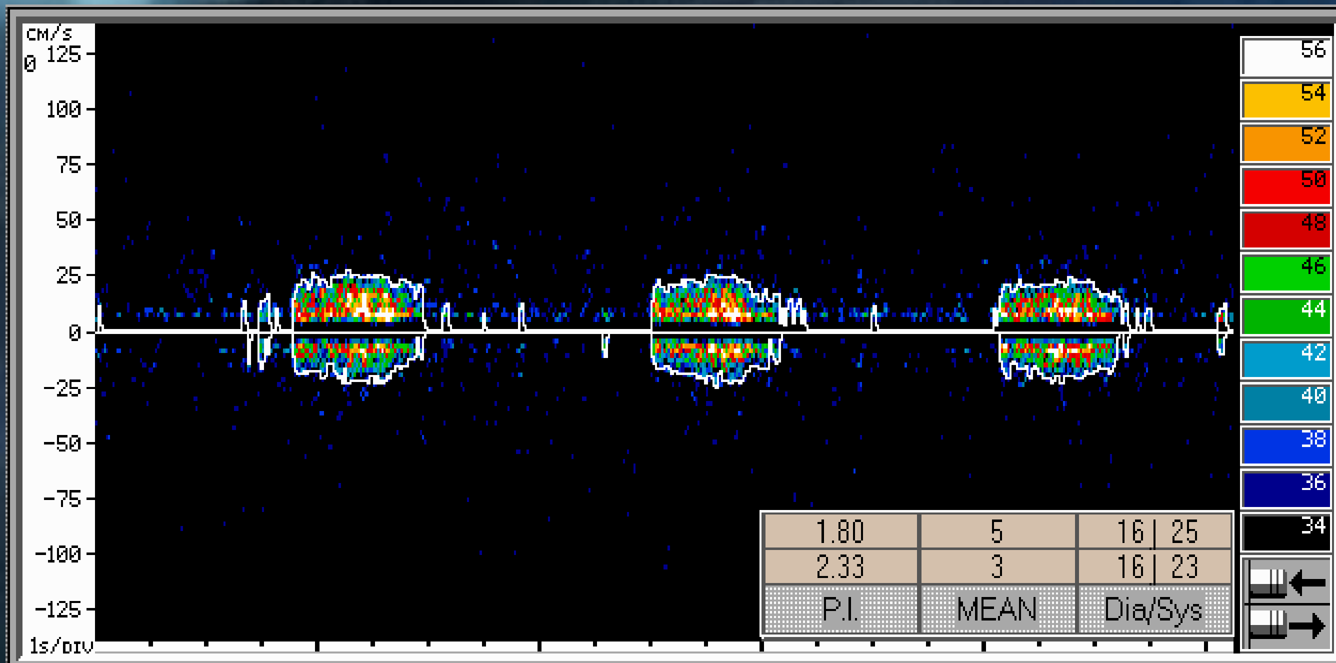


The waveform above baseline has an upward systolic up-stroke. This waveform has to be compared to a non-affected vessel in order to decide if only a slight delay in systolic acceleration is present. Regardless, this is NOT a blunted signal since a clear systolic complex is visualized.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

Waveform Recognition

A 62 year old woman with an M1-MCA occlusion.

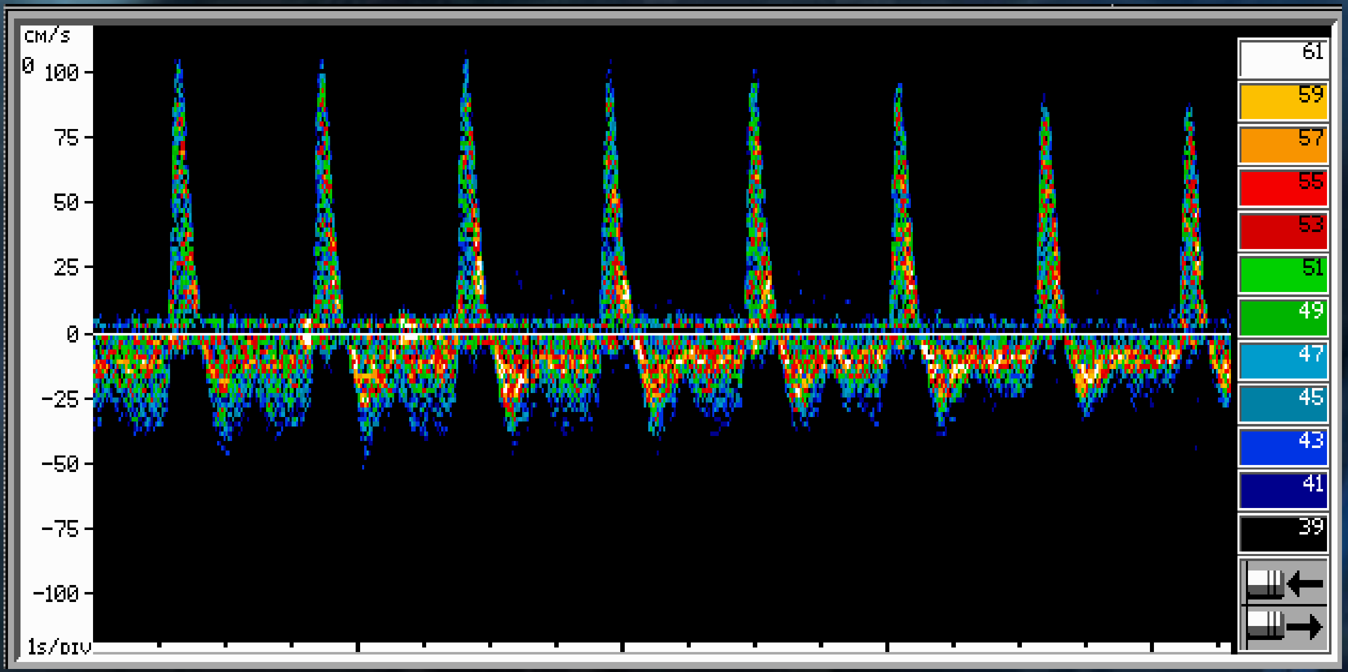


This is a minimal bi-directional signal with no end-diastolic flow. This waveform can be representative of a residual flow signal around MCA clot if collaborated by additional findings indicating occlusion at this location. Bruits and vessel intercept at nearly 90 degree angle should be considered as possible explanation.

Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.

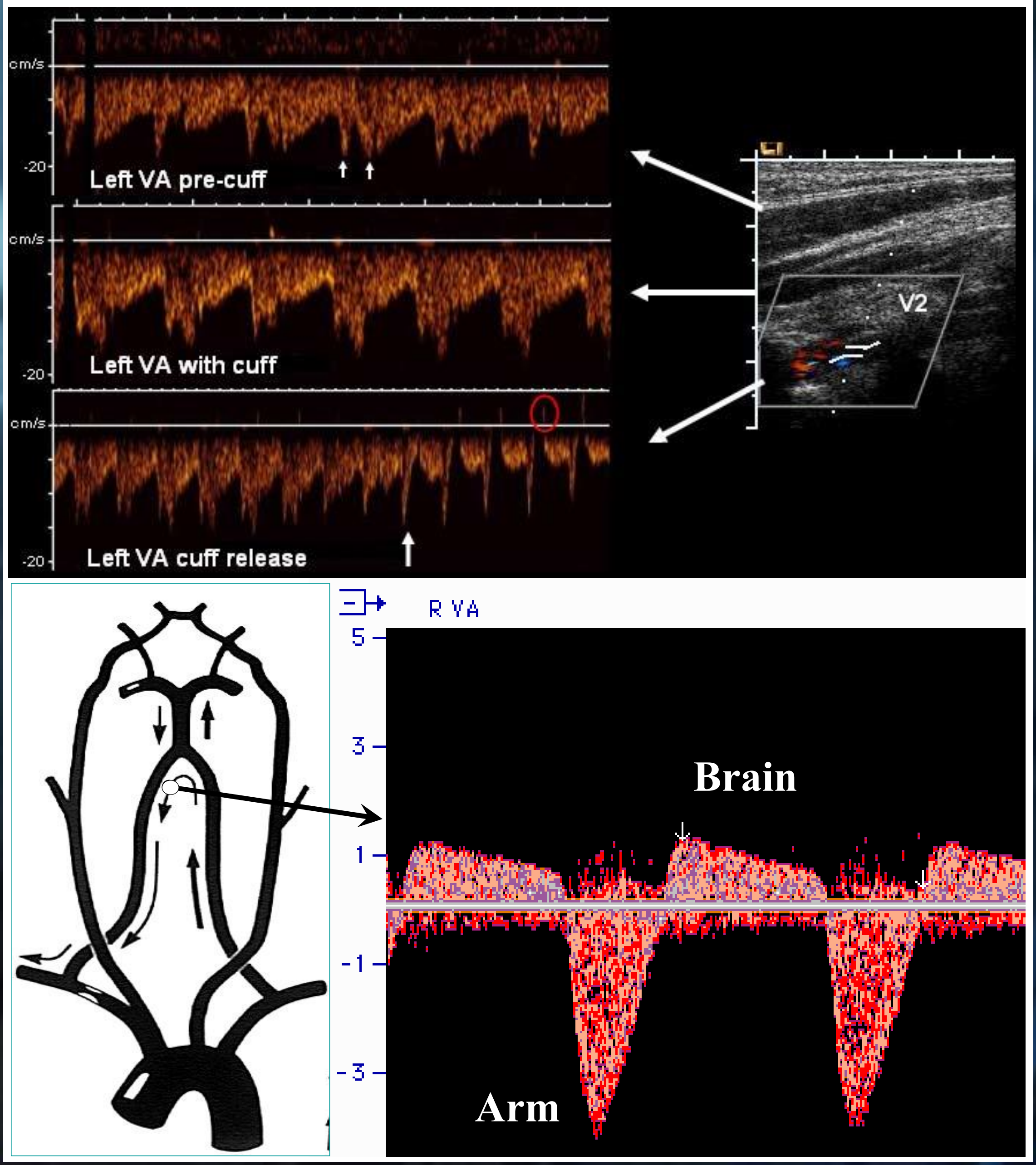
Waveform Recognition

A 41 year old woman with TBI and clinical progression to brain death.



Reverberating or oscillating flow signals. These waveforms represent an extremely high resistance to flow: (above baseline) sharp spikes with short flow reversal during closure of the aortic valve and no end diastolic flow; (below) reversed flow during entire diastoli.

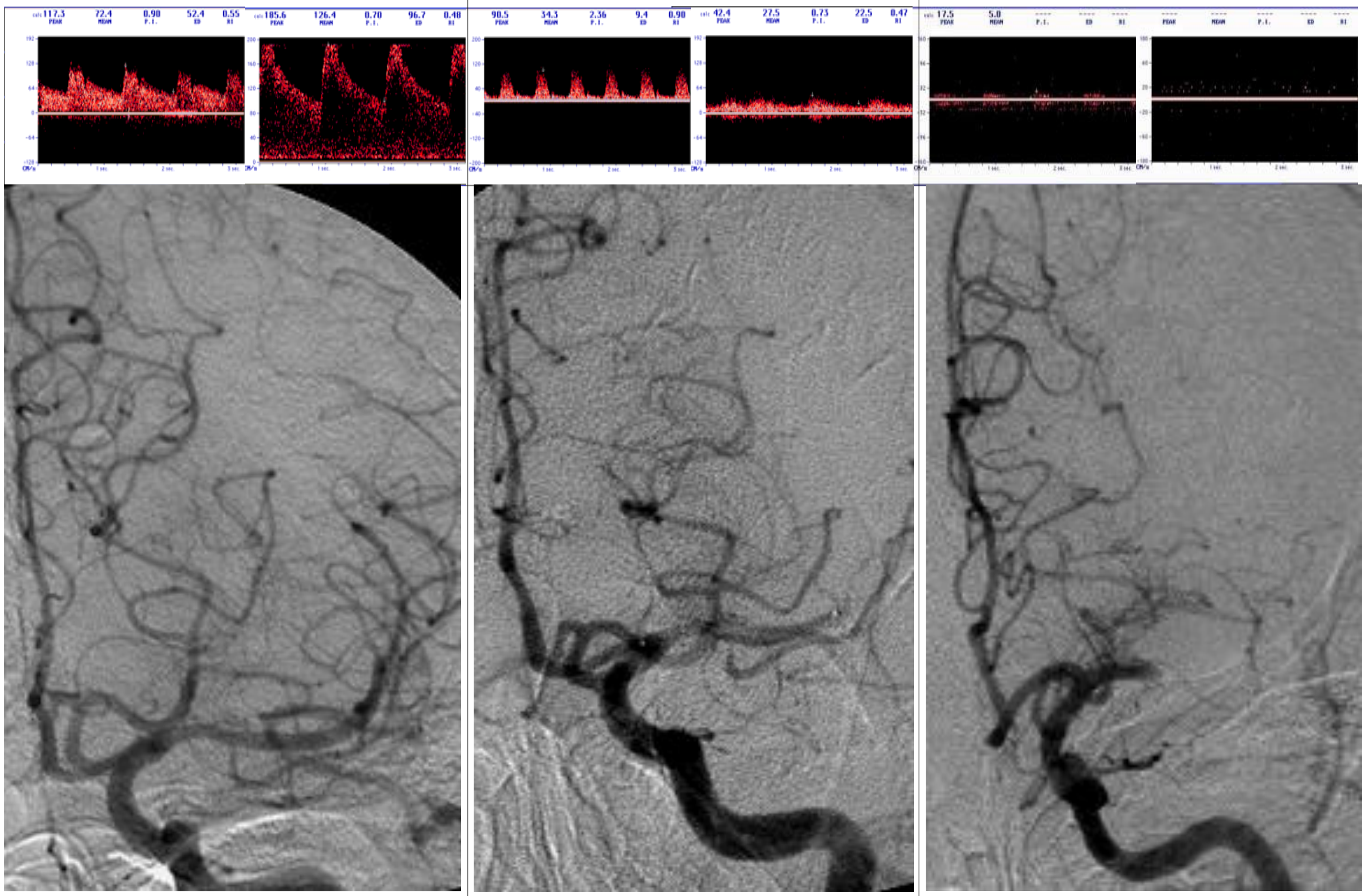
Alexandrov AV. Cerebrovascular Ultrasound in Stroke Treatment and Prevention. Blackwell: 2004.



J Vasc Ultrasound 2012;36;103-112.

Thrombolysis in Brain Ischemia (TIBI) waveforms

Normal	Stenotic	Dampened	Blunted	Minimal	Absent
V	IV	III	II	I	0



3	2	0-1

Thrombolysis in Myocardial Infarction (TIMI) flow grades

J Vasc Ultrasound 2012;36;103-112.

A Summary of Waveform Descriptions and Classifications

Condition	Waveform Description or Classification	Comments
Carotid artery stenosis	Waveforms helpful to suspect or confirm the significance of the stenosis: spectral narrowing, tardus parvus, and suppressed (high resistance) waveform in the pre-stenotic segment.	In addition, waveform analysis helps to identify cardiac influences on the flow profile and velocity findings (e.g., atrial fibrillation, valvular insufficiency or stenosis).
Subclavian, innominate, and vertebral artery disease	Steal waveforms (stages from latent to present at rest) are well described and established.[21]	Diagnostic criteria for the steal phenomenon are supported by waveform recognition and documentation.
Carotid artery occlusion	Drum-like waveforms; early systolic and end-systolic vessel wall movements	The presence of these waveforms may increase the confidence in diagnosing complete ICA occlusion.
Traumatic brain injury	Hemodynamic phases after injury (hypoperfusion, hyperemia and vasospasm) were defined.[22] Waveforms specific for each phase as well as for the mass effect need to be further determined.	Although the utility of ultrasound for this condition still needs to be established, underrecognized vasospasm and assessment of diastolic flow versus ICP and CPP are promising venues for further development of criteria for diagnostic waveform patterns.
Subarachnoid hemorrhage (SAH)	Waveforms consistent with vasospasm, hyperemia and increased ICP.	Low- and high resistance waveform patterns should be used to help refine velocity and ratio changes in patients with SAH.
Cerebral circulatory arrest	Waveforms across the spectrum of ICP changes are well defined (incomplete or complete cerebral circulatory arrest with oscillating or reverberating flow patterns)[18,19]	TCD is a confirmatory test to determine or rule out cerebral circulatory arrest based on assessment of the diastolic component and detection of specific waveforms indicating cessation of meaningful antegrade flow.
Extra- and intracranial arterial occlusions and high-grade stenoses	Waveform patterns of flow diversion, compensatory vasodilation and flow collateralization are defined as well as other waveforms pointing to either proximal (blunted/ delayed flow acceleration) or distal (increased resistance in a branch vessel) lesions[4]	Waveform changes particularly with lesions not directly accessible with ultrasound are very helpful (e.g., distal ICA stenosis, ICA dissection, siphon lesions, M2 MCA lesions, etc).
Acute ischemic stroke	Thrombolysis in Brain Ischemia (TIBI) classification of the residual flow using 6 types of waveforms (absent, minimal, blunted, dampened, stenotic, and normal)[20]	Waveform analysis helps to quickly determine the presence and persistence of an arterial occlusion and completeness of focal recanalization/ tissue reperfusion at bedside.

J Vasc Ultrasound 2012;36;103-112.