Peripheral Arterial Doppler Waveform Terminology

Introduction:

This guidance was prepared by the Professional Standards Committee (PSC) of the Society for Vascular Technology (SVT) as a template to aid the clinical vascular scientist / vascular sonographers and other interested parties. It can be used in conjunction with locally agreed protocols. It may be used in part or in its entirety with suitable additions made by local policy implementers, and should be read in combination with the following SVT guidelines when setting up an arterial scanning service:

Vascular Ultrasound Service Specifications:

Suggestions for improving these guidelines are welcome and should be sent to the Chair of the PSC; see www.svtgbi.org.uk for current Chair details.

Purpose:

The purpose of this guidance is to homogenise, standardize and clarify key descriptions of the Doppler waveform morphology, so that vascular scientists and other interested parties, use the same nomenclature when managing peripheral arterial disease (PAD) patients.

History:

Characterization of peripheral arterial waveforms is essential to the diagnosis of vascular disease. The diverse terminology of arterial Doppler waveforms produces a persistent problem and a source of confusion in clinical practice. [(2), (3), (6), (7), (8), (9)]

Although triphasic, biphasic, and monophasic waveform terminology has been used by medical and sonography professionals for more than five decades, definitions for these terms are inconsistent, contradictory, or non-existent. [(2), (3), (7), (8), (11).]

1. Arterial Nomenclature

Arterial spectral Doppler waveforms should be reported using key major descriptors:

Direction of flow,
Phasicity,
and **Resistance.**

Modifier terms may be incorporated to provide additional information about waveform appearance

Consensus:

• The reference baseline for spectral Doppler waveforms will refer to the zero-flow baseline

• All waveforms will be described using key descriptors and modifiers

• Optimization techniques should be used to provide quality Doppler waveforms for accurate interpretation

• Waveform descriptors and modifiers, velocity measurements, and image descriptors are test findings, not interpretations.

Note: Due to many parts involved with vascular ultrasound interpretation, vascular scientists, radiologists, vascular surgeons, sonographers, the waveform contours can be interpreted differently by different physicians and are often a source of confusion and misunderstanding, potentially leading to suboptimal care.

For the ease of clinical communication, terms that do not exactly follow the above consensus have been used. E.g., “triphasic above zero line”. It is important to offer from one hand, clear understanding of the clinical significance of the findings and from the other to educate for harmonisation purposes,

1.1. Direction of flow: Can be **antegrade, retrograde, bidirectional, or absent.**

1.2. Phasicity: is described using the terms **multiphasic and monophasic**.

Multiphasic waveforms cross the zero-flow baseline and contain both forward and reverse velocity components.
Monophasic waveforms do not cross the zero-flow baseline. However, AVS encouraged to interpret at report additional characteristics of the waveform (Table 3) to ensure the correct diagnosis of the presence, absence or severity of disease.

There is a hybrid waveform that is monophasic but has features of both high and low resistivity as it contains both brisk downstroke but also continuous forward flow throughout diastole. This waveform has been variably labelled the ‘biphasic’ or “above zero line biphasic/triphasic” waveform in several prior publications [(8).]

1.3. Resistance is described as demonstrating **high, intermediate, or low** resistance.

High-resistive waveforms have a sharp upstroke and brisk downstroke and may be either multiphasic or monophasic.
Intermediate resistive waveform is a hybrid waveform that is monophasic but has features of both high and low resistivity as it contains both brisk downstrokes but also continuous forward flow throughout the diastole. It can also be described as “**hyperaemic**”.
Low-resistive waveforms contain a prolonged downstroke in late systole with continuous forward flow throughout diastole without an end-systolic notch. Low-resistive waveforms are monophasic.

1.4. **Additional characteristic** terms may also be used

- Upstroke (rapid, with Systolic rise time <100msec or prolonged with low rise time with systolic rise time >140msec) [(1), (2), (4), (5), (6)]
- Spectral broadening
- Stenotic. At the stenosis site
- High Resistive (Staccato US) Pre-occlusion or pre-significant stenosis
- Dampened. Post-stenosis or post-occlusion
- Flow reversal/retrograde

The main descriptor, and additional modifier terms, and their descriptions are listed in Tables 1, 2 and 3.

2. Peripheral Arterial Circulation.

Multiple physiologic factors proximally, distally and at the site being examined contribute to the morphology of the Doppler waveform. Metabolic demands of the tissue bed, changes in pressure, changes in resistance, wave propagation, and wave reflection all impact waveform patterns.

2.1. Normal peripheral arterial waveforms.

The peripheral arterial circulation supplies the muscular tissues of the lower extremities. At rest, the normal Doppler display is a triphasic flow pattern -excluding Aorta- with a clear spectral window. This characteristic pulsatile waveform shape is due to a combination of compliant distensible arterial walls and pulse wave reflections from the periphery. It may be possible to see four phases in young healthy adults.

In elderly patients or patients with poor cardiac output, the waveform may be biphasic or monophasic. (Table 4).

Conditions that produce an increased flow to the limb muscles, such as exercise, increased limb temperature, and/or arteriovenous fistula, do so in part by dilating the arterioles in the muscle bed allowing forward flow throughout diastole. (Hyperaemic flow) Although the Doppler waveform generally demonstrates a narrow spectral bandwidth, some increase in spectral broadening may be noted dependent on the diameter of the arterial segment and the size of the Doppler sample volume (2) (Table 4).

2.2. Abnormal peripheral arterial waveforms.

When the degree of stenosis is sufficient to cause a pressure-flow gradient, it will produce loss of the reverse flow component and transition from a multiphasic to a monophasic flow. The severity of arterial compromise is reflected in the continual increase in peak systolic and end-diastolic velocities to a critical value consistent with a pre-occlusive lesion.

Waveforms with an increased systolic rise time are characteristic of disease proximal to the point of measurement. Distal to a stenosis, ischaemia in the tissue bed will result in vasodilation and decreased resistance. In addition, there is a decrease in distal pressure due to the pressure drop across the stenosis. This pressure drops along with the lower resistance resulting in increased diastolic flow throughout the cardiac cycle.

Conversely, high-resistance, low-volume flow waveforms are indicative of severe disease distal to the point of measurement. This is due to a reflected wave from the disease or occlusion.

Severe calcification of the arterial wall may also affect the shape of the recorded Doppler waveform due to changes in vessel compliance as the vessels become very rigid. This is commonly observed in the tibial vessels of diabetic patients, where the waveform shape may become monophasic with the continuous forward flow throughout the cardiac cycle (Table 5)

3. Interpretation and Reporting:

Standardized description of waveforms allows the waveform display to be recreated in words, providing useful information relevant to the clinical indication for the examination.

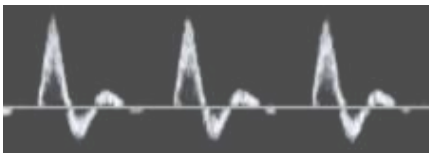
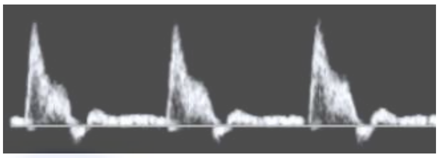
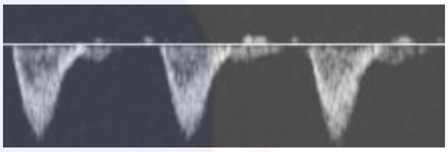
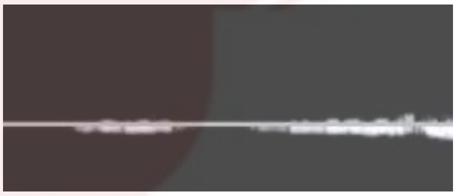
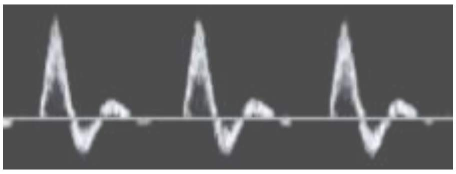
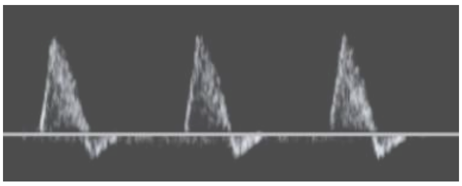
All interpreting vascular scientists should be able to describe Doppler waveforms, be able to identify the changes which occur with physiologic and disease states, and effectively communicate these waveform characteristics to other parties so that consistent information is given to referring providers

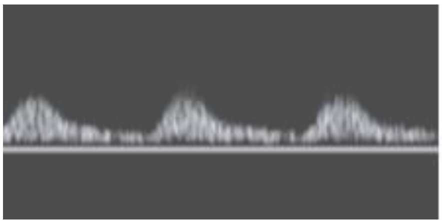
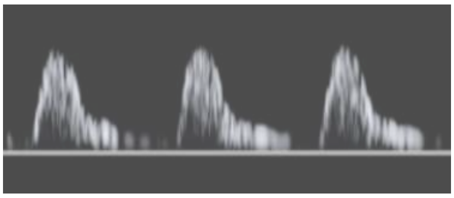
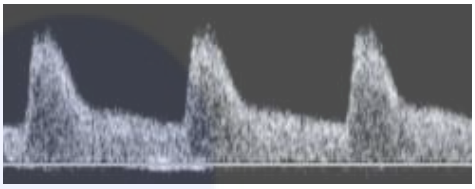
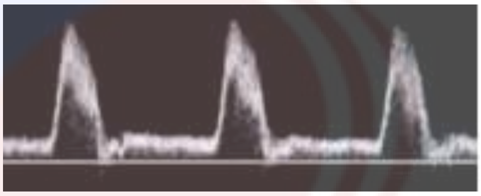
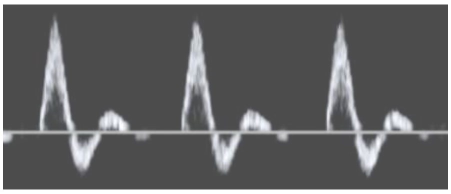
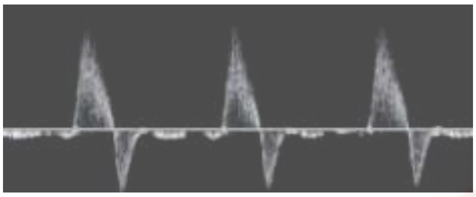
Additional waveform findings, should be used along with exam-specific, validated diagnostic criteria to determine the final interpretation or conclusion of the vascular study.

Table 1.
Main descriptive terms

Arterial Waveforms	
M**ajor descriptors**	• Flow direction (antegrade, retrograde, bidirectional, absent) • Phasicity (multiphasic, monophasic) • Resistance (high, intermediate, low)
Additional descriptor terms	• Upstroke (rapid, with Systolic rise time <100msec or prolonged with rise time with systolic rise time >140msec) • Spectral broadening Stenotic. At the stenosis site • High Resistive (Staccato) Pre-occlusion or pre-significant stenosis • Dampened. Post-stenosis or post-occlusion • Flow reversal

Table 2.
Peripheral Arterial Waveform Main terms.

Flow direction	
Antegrade: Alternate Term: Forward Flow. Blood flows in the normal direction for the artery being evaluated	
	
Retrograde: Alternate Term: Reverse Flow. Blood flows opposite to the normal direction for the artery being evaluated	
Bidirectional: Alternate Term: To-Fro. Blood flow enters and leaves a contained space via the same orifice	
Absent: No blood flow is detected with an absent spectral Doppler signal.	
Phasicity	
Multiphasic: Alternate Terms: Triphasic, Biphasic. Waveform crosses the zero-flow baseline and contains both forward and reverse velocity components	
	

Monophasic: Waveform does not cross the zero-flow baseline throughout any part of the cardiac cycle, blood flows in a single direction. Note: If waveform does not cross the zero-flow baseline it is considered monophasic	
	
	
	
	
<u>Resistance</u>	
High resistive: Key features: sharp upstroke and brisk downstroke, with or without diastolic flow reversal	
	

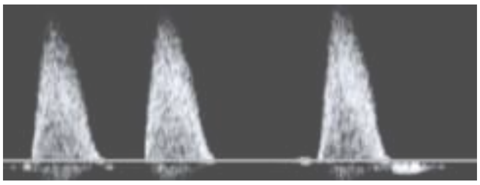
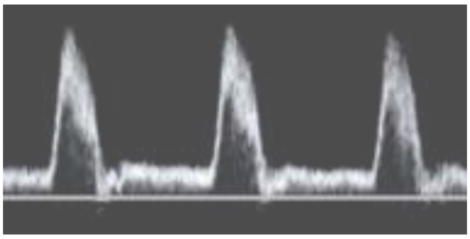
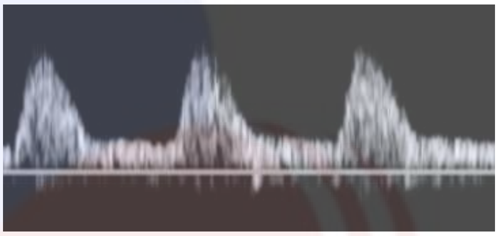
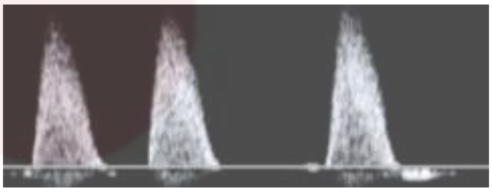
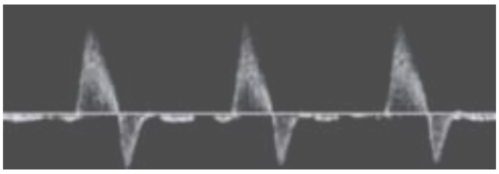
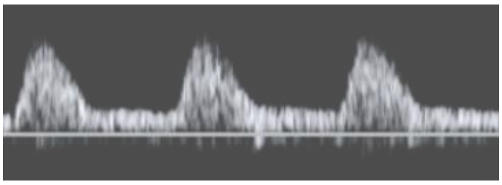
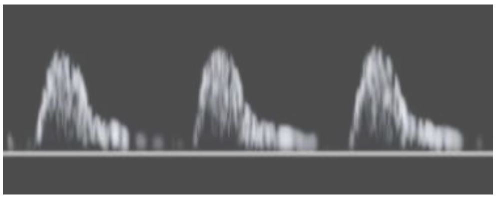
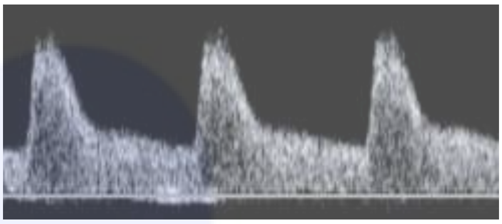
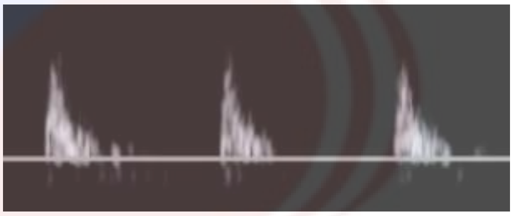
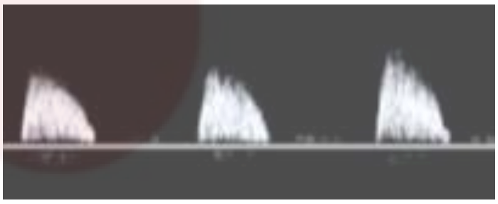
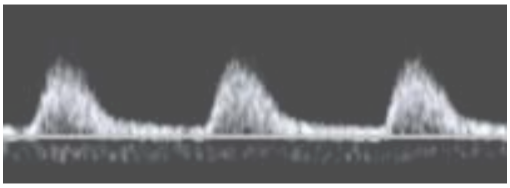
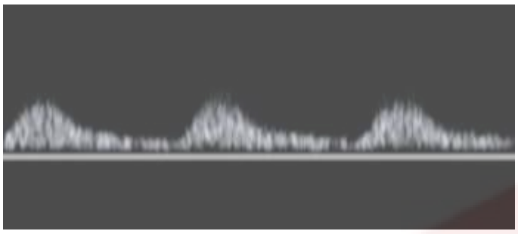
	
Intermediate resistance: Hyperaemic: Key features: sharp upstroke, brisk downstroke, visible presence of an end systolic notch and continuous forward flow throughout diastole that is above the zero-flow baseline. The waveform pattern suggests vasodilation and can be the result of exertion (exercise), increased temperature, vasodilator drugs, or inflammation.	
Low resistive: Key features: a prolonged downstroke in late systole and continuous forward flow throughout diastole. Note: In contrast to intermediate resistance, the low-resistive waveform contains a continuous and prolonged diastolic forward.	

Table 3.
Waveform additional characteristics and definitions

Rapid upstroke: Nearly vertical slope or steep rise to peak systole. Acceleration time (AT) or Systolic Rise Time <100ms has been used for the common femoral artery (measured from start of systole to mid-systole).	
	
Prolonged upstroke: Alternate Terms: Damped, Tardus, Delayed. Abnormally gradual slope to peak systole. Acceleration time (AT) >140msec (2, 14) has been used for the lower extremity common femoral artery.	

	
	
Spectral Broadening: Alternate Terms: Non-Laminar, Turbulent, Disordered, Chaotic. Widening of the velocity band in the spectral waveform; a “filling in” of the clear “window” under the systolic peak. Note: Spectral broadening is commonly seen in turbulent flow but can also be seen in the absence of turbulence	
Steep High Resistive A very high-resistance pattern with short “spike” of velocity acceleration and deceleration followed by short and low-amplitude diastolic signal reflecting low antegrade flow	
	
Damped/Poor damped: Alternate Terms: Parvus et Tardus, Attenuated, Blunted. Combined finding of an abnormal upstroke (delayed) and peak (broad), most often with decreased velocity	
	

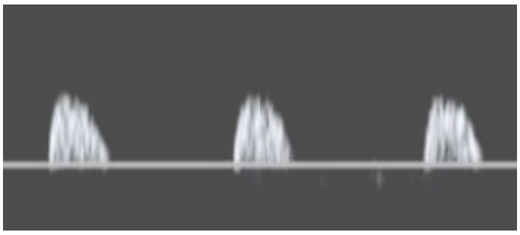
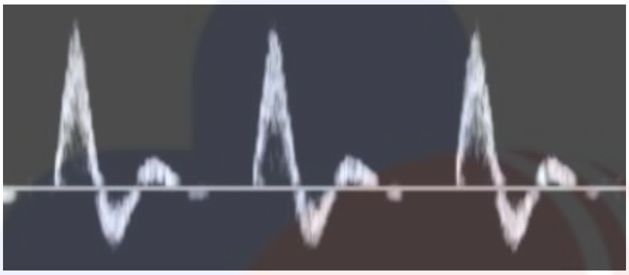
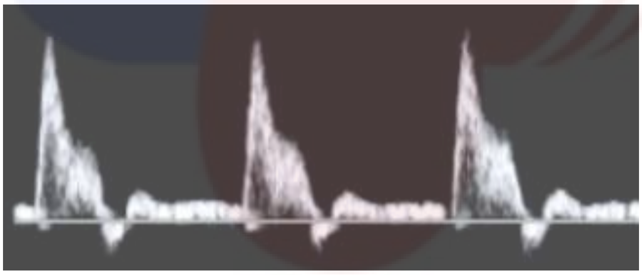
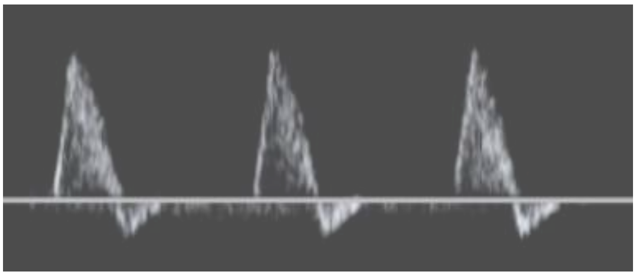
	

Table 4.
Normal Peripheral Arterial Waveforms.

In the resting state, the normal waveform of all peripheral arteries is multiphasic with rapid systolic acceleration, sharp systolic peak, reverse diastolic flow, and low, or absent, end-diastolic forward flow



Normal Hyperaemic peripheral arterial waveforms following exercise or resulting from increased body temperature. The increased flow demand and decreased vascular resistance associated with exercising muscle, increased body temperature, or focal inflammation results in continuous forward flow. PSV can increase significantly, because of exercise even when the artery is normal.

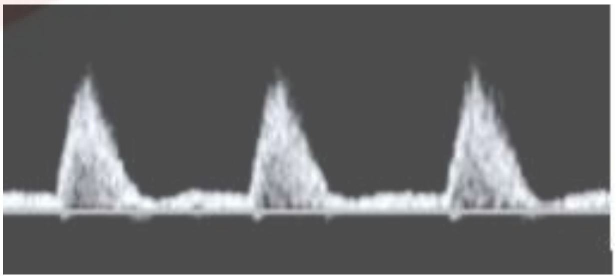
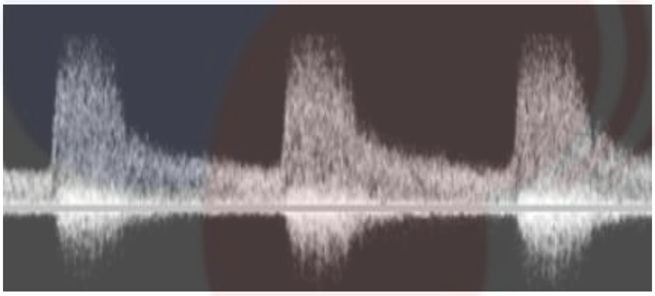
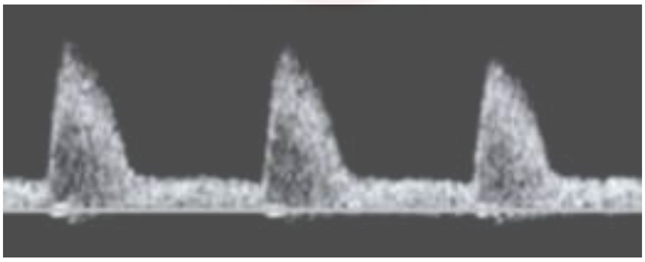
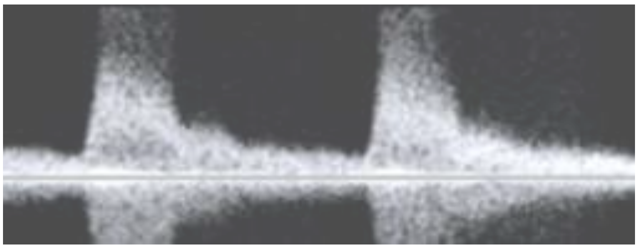
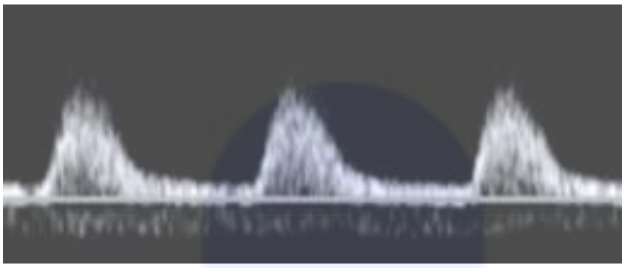


Table 5.
Basic Abnormal waveforms

Significant lumen stenosis (>50% diameter reduction). **Antegrade, monophasic, stenotic, rapid upstroke, spectral broadening, high PSV.**
When the lumen of the artery is significantly narrowed, a pressure-flow gradient is present at the stenotic site. The early diastolic reverse flow component is commonly lost (may be residual in high-velocity state with extensive collateralization) and rapid upstroke is presented with continuous, monophasic forward flow and increased PSV (ratio >2). Spectral broadening is usually present.



Distal to significant flow limiting stenosis/occlusion:

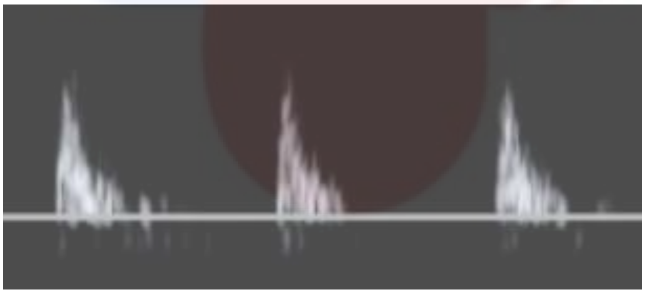
Antegrade, monophasic, low resistive, damped.

Waveform is monophasic with prolonged (damped) upstroke and PSV is decreased. Spectral broadening is present.



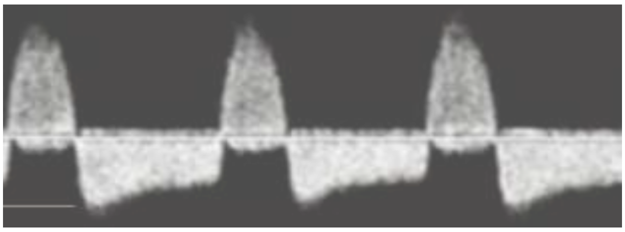
Proximal to occlusion:
Antegrade, monophasic, steep high resistive

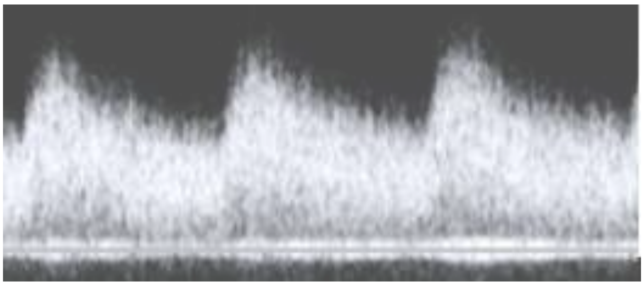
The waveform is characterized by steep rapid upstroke and is of high resistance or intermediate resistance.



Pseudoaneurysm.
Biphasic/Bidirectional, rapid upstroke and downstroke, spectral broadening

Flow is bidirectional (to-fro) through the neck, or tract of the arterial pseudoaneurysm. The waveform has a rapid systolic upstroke with exaggerated deceleration, and an elongated and prominent reverse flow component



Arteriovenous fistula: **Antegrade, monophasic, low resistive, with spectral broadening**
Blood flow from a high-pressure artery into a low-pressure vein result in spectral broadening and elevated systolic and diastolic velocities. Continuous forward flow is noted throughout the cardiac cycle. Ns


References:

1. Burnham SJ, Jaques P, Burnham CB. Noninvasive detection of iliac artery stenosis in the presence of superficial femoral artery obstruction. J Vasc Surg. 1992;16(3):445-451; discussion 452
2. Guilcher, A., Lanéelle, D., Hoffmann, C., Guillaumat, J., Constans, J., Bressollette, L., Le Hello, C., Boissier, C., Bura-Rivière, A., Jaquinandi, V. and Omarjee, L., 2021. Comparison of the use of arterial Doppler waveform classifications in clinical routine to describe lower limb flow. Journal of Clinical Medicine, 10(3),
3. Kim, E.S., Sharma, A.M., Scissons, R., Dawson, D., Eberhardt, R.T., Gerhard-Herman, M., Hughes, J.P., Knight, S., Marie Kupinski, A., Mahe, G. and Neumyer, M., 2020. Interpretation of peripheral arterial and venous Doppler waveforms: A consensus statement from the Society for Vascular Medicine and Society for Vascular Ultrasound. Vascular Medicine, 25(5),
4. Mahé, G., Boulon, C., Desormais, I., Lacroix, P., Bressollette, L., Guilmot, J.L., Le Hello, C., Sevestre, M.A., Pernod, G., Constans, J. and Boissier, C., 2017. Statement for Doppler waveforms analysis. Vasa, 46(5), pp.337-345.
5. Nicolaides AN, Yao JST. Investigation of vascular disorders. Edinburgh: Churchill Livingstone, 1981
6. Oates, Crispian Cardiovascular Haemodynamics and Doppler Waveforms Explained. Paperback (09 Jun 2008)
7. Omarjee, L., Stivalet, O., Hoffmann, C., Scissons, R., Bressollette, L., Mahé, G. and Jaquinandi, V., 2018. Heterogeneity of Doppler waveform description is decreased with the use of a dedicated classification. Vasa, 47(6), pp.471-474.
8. Scissons R. Traditional Peripheral Arterial Doppler Waveform Descriptors: Are They Still Worth Teaching? Journal of Diagnostic Medical Sonography. 2012;28(2):51-57. doi:10.1177/8756479311435524
9. Shaalan, W.E., French-Sherry, E., Castilla, M., Lozanski, L. and Bassiouny, H.S., 2003. Reliability of common femoral artery hemodynamics in assessing the severity of aortoiliac inflow disease. Journal of vascular surgery, 37(5), pp.960-969.
10. Spronk, S., den Hoed, P.T., de Jonge, L.C., van Dijk, L.C. and Pattynama, P.M., 2005. Value of the duplex waveform at the common femoral artery for diagnosing obstructive aortoiliac disease. Journal of vascular surgery, 42(2), pp.236-242.
11. Zhao, R., Lanéelle, D., Gao, M., Fu, Y., Tong, Y., Scissons, R., Wen, C. and Mahé, G., 2020. Inter-rater reliability of 4-item arterial Doppler waveform classification system for description of arterial Doppler waveforms. Frontiers in cardiovascular medicine, 7, p.584274.
12. Zierler, R.E., 2012. Strandness's duplex scanning in vascular disorders. Lippincott Williams & Wilkins.