Clinical evaluation of Doppler signals

1 CLINICAL DIAGNOSIS OF PERIPHERAL VASCULAR DISEASE CAN BE CONFIRMED BY DOPPLER EXAMINATION.

2 WAVEFORM PATTERNS CAN PROVIDE GOOD REFERENCE DATA AND SUPPORT DIAGNOSIS.

3 A POLE TEST IS A RELIABLE METHOD OF ASSESSMENT WHEN CALCIFICATION IS PRESENT.

4 TOE PRESSURES ARE MORE RELIABLE THAN ANKLE PRESSURES IN PATIENTS WITH DIABETES.

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Introduction

The hand-held Doppler unit is now widely used in clinical practice by many health professionals to assess blood flow in peripheral vessels. Although it provides invaluable information, it is still essential for practitioners to have a clear understanding of the anatomy and physiology involved if interpretation of this information is to be clinically relevant.

The history and mechanics of Doppler ultrasonography in the diagnosis of vascular disease are well described by Coleridge-Smith (1996).

This article explains a few simple concepts to guide practitioners in interpretation of the information obtained from a hand-held Doppler probe.

REVIEW OF THE CARDIAC CYCLE

With each cardiac cycle the left ventricle contracts, ejecting blood into the aorta to begin its journey around the body. The blood forced into the aorta meets resistance from the blood already within the vessels and from vasoactivity. This resistance to forward flow is called 'peripheral resistance' (*Figure 1*).

Because of peripheral resistance, not all of the ejected blood can be immediately squeezed down the arterial tree; that which remains distends the walls of the aorta and vessels closest to the heart. The distension of these arteries is made possible by the large amount of elastin within the vessel walls.

This stretching followed by elastic recoil of the arterial walls allows the hydraulic pressure close to the heart to remain at a constant high value, and results in the propagation of a smooth pressure wave.

DOPPLER SOUNDS

The pulse that we feel is a pressure wave generated by the heart as it expels blood into the aorta. The character of this pulse is dependent upon many interrelated factors, such as cardiac activity, arterial state and peripheral resistance.

The noises that we hear when using the Doppler machine are generated by the pressure waves, and have been likened to a steam locomotive shunting out of its yard in three-time rhythm or 'whur–ahh–orr', denoting a triphasic beat (*Figure 2*).

The arterial signal is multiphasic, consisting of three parts:

- An initial forward flow rising to a peak at the peak of systole
- A drop from peak systole to reverse flow in diastole
- Finally, another period of forward flow in diastole.

These last two components reflect the elastic recoil of the stored energy resulting from vessel distension at peak systole. This signal is described as *triphasic*. The typical waveform generated has a mountain range appearance (*Figure 2*).

Elderly people commonly have a *biphasic* signal. This characteristically has two parts: the forward flow component at systole, followed by a second forward flow in diastole. This is a 'normal' signal; it occurs with ageing and is caused by early atherosclerosis as the vessel walls lose some of their elasticity.

A biphasic signal may also be heard if peripheral resistance is high, e.g. in cold conditions when vasoconstriction is present (*Figure 3*). Note that there is no reverse flow and the

Figure 1. Diagrammatic representation of peripheral resistance and vessel distension.

Figure 2. Typical triphasic waveform.

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peaks are blunted.

A *monophasic* signal gives only one sound. This represents a single forward flow component during systole. Monophasic signals may arise when there is vessel stenosis or the vessels are rigid rather than stenosed.

VESSEL STENOSIS: In this situation there is insufficient flow within the vessel during diastole to generate a signal. This denotes vessel disease proximal to the signal site. This may be caused by an isolated stenosis or multiple stenoses.

Other clinical features of vascular disease, such as claudication, low ankle systolic pressure and skin changes may be present (*Figure 4*). Note that there is no second forward or reverse flow, and a very blunt systolic peak. The sound heard would be lower in pitch than the triphasic or biphasic signal and the signal would be more subtle.

RIGID VESSELS: In this situation, the sound generated has been likened to that of soldiers marching. The signal is monophasic and the pressures are high. The waveform may be similar to that shown in *Figure 5* — in contrast to the smooth rhythmic nature of a normal pulse signal. This is due to the elastic nature of the vessel walls, as demonstrated in the triphasic sound and waveform (Goethals and Brutsaert, 1981).

PITCH: The pitch of the signal is also worthy of note. A high-pitch sound signifies high velocity flow, and a low-pitch sound low velocity flow.

In the diseased state, the signal generated can be almost continuous and sound similar to the venous signal, i.e. 'a howling gale' (*Figure 6*).

Problems commonly encountered in obtaining a good signal are shown in *Table 1*.

WAVEFORMS

Figures 7-11 show a series of diagrammatic representations of waveforms to illustrate the basic principles of their interpretation. In an article of this nature it is impossible to explore in depth all of the possible variations.

The basic waveform pattern obtained by the Doppler probe is represented as a simple graph, in which the vertical line represents either blood flow velocity or the mean Doppler frequency shift.

The horizontal line re-presents time in seconds (*Figure 7*). All recordings above the baseline (horizontal line) indicate forward flow and all recordings below the baseline signify reverse flow.

The 'normal' arterial waveform pattern shows an initial tall, sharp, mountain peak above the baseline, dropping to a corresponding, but smaller, valley below the baseline, and finally rising to a small hill above the baseline. There then follows a horizontal line running just above baseline before the next mountain peak starts.

TABLE 1. COMMON PROBLEMS IN OBTAINING A GOOD SIGNAL

Incorrect probe angle	The correct angle of the probe is 45–60° to the skin surface. The probe should be pointed towards the direction of blood flow
Wrong probe selection	The probe selected should be related to the depth of the vessels being examined. As a guide the foot arteries require a 8MHz probe, digital vessels a10MHz probe and popliteal or femoral arteries a 5MHz probe
Insufficient coupling gel	A poor signal with noisy artefacts is obtained if meagre amounts of gel are used. The gel should also be as free from air as possible – not KY jelly
Venous contamination	Move the probe until the clearest pulsatile signal is obtained. Remember that veins are located next to arteries. If you suspect that you are listening to a venous signal (continuous howling gale), ask the patient to hold his/her breath; if the signal disappears you are listening to venous blood flow
Pressure of probe on skin	This will affect the flow, and consequently the sound and waveform, or will occlude the vessel so that the signal disappears
Probe motion	Moving the probe during examination will alter or lose the signal

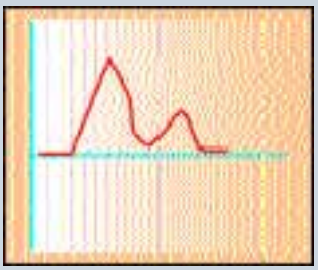

Figure 3. Biphasic waveform.

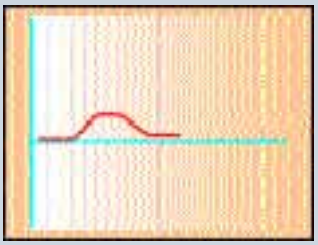

Figure 4. Monophasic waveform.

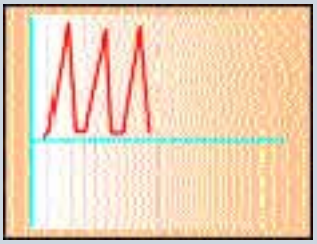

Figure 5. 'Staccato' type waveform from a rigid tube.

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The height of the first 'mountain', which represents peak systole, is dependent upon cardiac output and peripheral resistance.

In the presence of arterial disease, the reverse flow recording (under the baseline) is lost and the two peaks of forward flow are shallower. When the disease process is more evident, the second forward flow component is lost. Also, in the presence of arterial disease the peak forward flow rises but is notably 'dampened', i.e. wider and flatter.

The turbulent flow distal to a stenosis gives rise to a wide range of Doppler shift frequencies, known as spectral broadening. The height of the waveform will be decreased as a consequence of the reduced pressure and velocity within the affected artery.

A waveform that is raised well above the baseline would suggest that the peripheral arteries are dilated (*Figure 8*).

The presence of a continuous wiggly line below the baseline throughout the recording signifies that the signal is contaminated with venous flow, i.e. the Doppler probe is capturing both arterial and venous blood flow (*Figure 11*).

Figure 12 shows a series of waveforms illustrating the changes that may be observed at sites before, immediately over, and just after an arterial stenosis. It can be helpful to try to simulate the sounds you would expect to hear as you look at each diagram in turn.

Like all clinical diagnostic modalities, the waveforms recorded are subject to operator error. It is a worthwhile exercise to see what happens when the angle or position of the probe is altered, when pressure is applied, when insufficient coupling medium is used, and when many other variables are introduced. Despite this potential for error, however, the information obtained from a standardised approach can be very useful, particularly in combination with other clinical findings.

It is also useful, when determining the extent of vessel disease, to compare the findings from one limb with those from the other limb and with more proximal signals.

Additional non-invasive diagnostic techniques

Measurement of ankle/brachial pressure indices (ABPIs) is frequently employed to determine the presence of arterial disease in the clinical situation (Stubbing et al, 1997; Livingston, 1994).

Although ABPI is a very useful tool, it has a major limitation when applied to people with diabetes. Calcification of the tunica media (smooth muscle

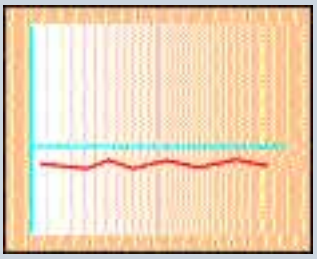

Figure 6. Venous signal – the sound of 'a howling gale'.

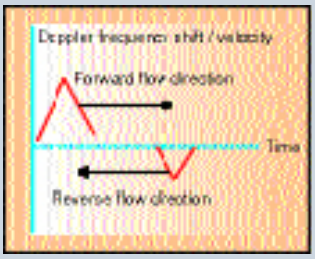

Figure 7. Basic anatomy of a waveform diagram.

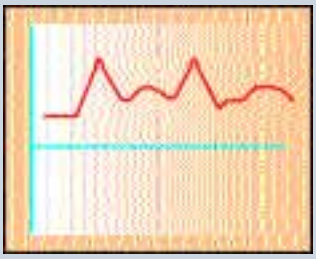

Figure 8. Waveform obtained during vasodilation.

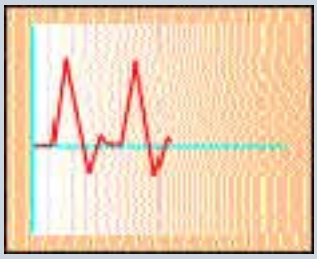

Figure 9. Waveform obtained during vasoconstriction.

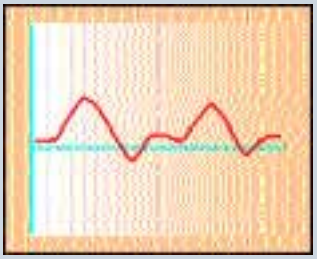

Figure 10. Waveform from an artery at room temperature.

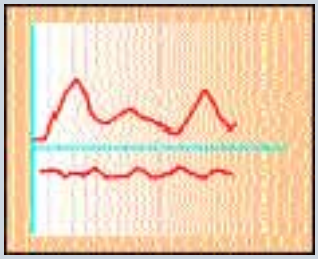

Figure 11. Waveform showing a biphasic pattern with venous contamination.

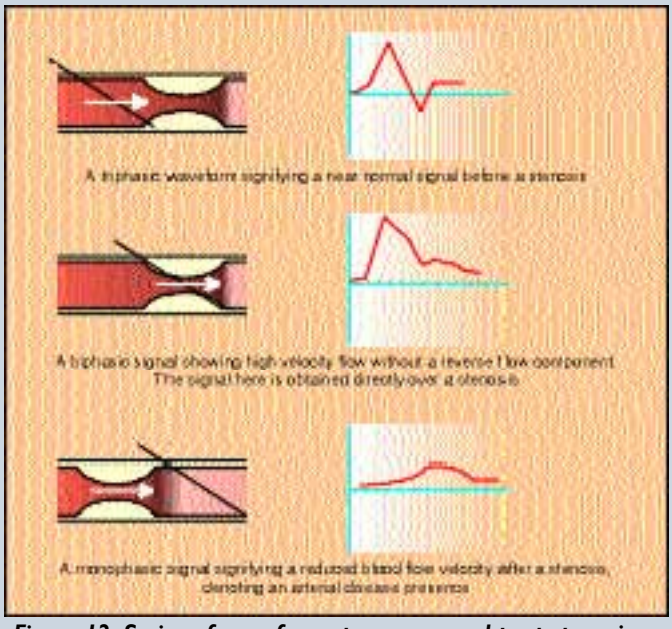

Figure 12. Series of waveforms pre-, over and post-stenosis.

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layer) is common in this patient population (Young et al, 1993). Hence the vessel wall of affected patients is not readily collapsed by the sphygmomanometer cuff, and an erroneously high systolic ankle pressure is frequently obtained.

Diabetes and non-invasive vascular assessments

In patients with diabetes the arteries from the knee to the ankle are aggressively affected by atherosclerosis. In addition, as previously stated, arterial calcification is common and ABPIs are frequently unreliable.

In this situation there are two useful clinical tests that can be performed, which overcome these difficulties and enable assessment of the arterial inflow to the diabetic foot. One is a modified Buerger's test, called the 'pole' test, and the other is toe systolic blood pressure measurement.

Pole test

This test relies on the fact that pressure within a healthy artery remains relatively constant, irrespective of whether the limb is raised or dependent. In the presence of arterial disease, however, pressure within the limb will drop when the limb is elevated above heart level.

This can be determined in patients by listening to the Doppler signal obtained at a pedal pulse site while gradually moving the limb from a supine position to above heart level. If no change in the signal is detected, there is no significant arterial inflow deficit; however, if the signal fades with a change in phasicity, then arterial disease is indicated.

It is important to recognise that a change in the position of the probe will cause the signal to change, leading to false results.

This test is called the pole test because, traditionally, a graduated pole was placed at the foot end of the patient and the height at which the signal disappeared was recorded. The lower the height the more advanced the arterial disease (Smith et al, 1994).

Toe pressures

Systolic pressure measurement is more reliable if performed at the level of the digits, as the digital arteries are less frequently affected by arterial calcification (Holstein, 1984; Orchard and Strandness, 1993).

Many of the techniques for measuring toe pressure are best suited to the research environment rather than to the clinical workplace, e.g. photoplethysmography, strain gauge plethysmography and laser Doppler flowmetry (Neilsen et al, 1972; Lyons et al, 1994; Hoffman et al, 1991).

However, it is possible to detect digital blood flow using a hand-held Doppler with a 10 MHz probe, and to obtain a toe pressure using a toe cuff (Carter, 1985). The toe cuff is identical in design to the standard brachial cuff, but much smaller – about 2.5–3.6 cm wide (Hoffman et al, 1991; Beinder et al, 1992).

The technique for measuring toe pressure is identical to that used at the ankle, but requires greater dexterity and experience. It is generally easier to measure pressures in the big toe because of its larger size.

It is also important to be aware that toe pressures are lower than those at the ankle. One of the criteria for defining critical limb ischaemia is an ankle pressure of <50 mmHg in people without diabetes; in people with diabetes, however, critical limb ischaemia may be defined by a toe pressure of <30 mmHg.

The normal value for a toe/brachial index is >0.7. A value of <0.65 would indicate arterial disease (Lyons et al, 1994).

Conclusion

Routine vascular assessment in patients with diabetes should include the use of Dopplers, possibly supplemented by waveforms. If arterial calcification is suspected the pole test or toe pressure measurement are invaluable. ■

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