

Hand-held Doppler Ultrasound: The assessment of lower limb arterial and venous disease

Kathryn Vowden BSc(Hons) RN DPSN(TV) Clinical Nurse Specialist, Department of Vascular Surgery,

Bradford Royal Infirmary and Lecturer, University of Bradford

Peter Vowden MD FRCS Consultant Vascular Surgeon, Bradford Royal Infirmary

Key Words

Doppler ultrasound, Assessment, ABPI, Leg ulcer management, Varicose veins

Introduction

Doppler ultrasound is frequently used as a screening tool when assessing patients for arterial disease.

The ankle brachial pressure index (ABPI) is derived from the highest of the two arm systolic pressures, taken as the best non-invasive estimate of central systolic pressure, and the highest ankle systolic pressure for each limb and can indicate both the presence and severity of arterial disease. The use of this equipment and ABPI calculation is now considered mandatory in leg ulcer

management and is used routinely in vascular assessment. An ABPI of 0.8 or higher is taken to indicate that, if appropriate, a limb is suitable for high compression bandaging.

A procedure maximising the accuracy of Doppler ABPI has been recognised for some time and has been restated by Vowden et al (1996a) (Table 1) and this, along with similar descriptions (Stubbing et al, 1997), now represents a standard for this investigation in nursing practice.

Doppler and ABPI

The origins of the ABPI are in the medical literature but the Doppler principle is based in physics and can be applied to any energy waveform.

Figure 1.
Large venous ulcer protected to allow application of sphygmomanometer cuff at ankle, Doppler probe positioned over Dorsalis Pedis artery.



Figure 2.
The arteries of the foot demonstrating the site of probe application for the PT, AT and DP arteries.

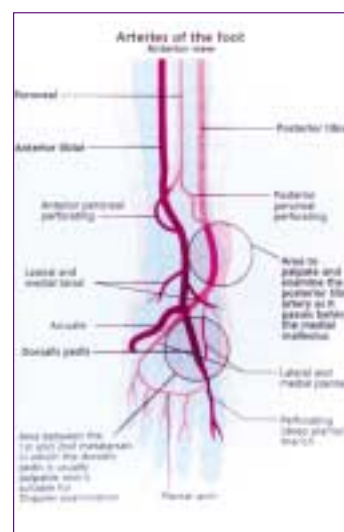


Table 1: Explain the procedure and reassure the patient and ensure that he/she is lying flat and is comfortable, relaxed and adequately rested with no pressure on the proximal vessels

1. Measure the brachial systolic blood pressure:

- Place an appropriately sized cuff around the upper arm
- Ensure that the equipment and the arm are at heart level
- Locate the brachial pulse and apply ultrasound contact gel
- Angle the Doppler probe at 45° and move the probe to obtain the best signal
- Inflate the cuff until the signal is abolished then deflate the cuff slowly and record the pressure at which the signal returns being careful not to move the probe from the line of the artery
- Repeat the procedure for the other arm
- Use the highest of the two values as the best non-invasive estimate of central systolic pressure and use this figure to calculate the ABPI

2. Measure the ankle systolic pressure:

- Place an appropriately sized cuff around the ankle immediately above the malleoli having first protected any ulcer or fragile skin that may be present (Figure 1)
- Examine the foot, locating the dorsalis pedis pulse (Figure 2) and apply contact gel
- Continue as for the brachial pressure, recording this pressure in the same way again with equipment at heart level
- Repeat this for the posterior tibial and if required the peroneal and anterior tibial arteries
- Use the highest reading obtained to calculate the ABPI for that leg
- Repeat for the other leg
- Calculate the ABPI for each leg using the formula below or look up the ABPI using a reference chart

$$\text{ABPI} = \frac{\text{Highest pressure recorded at the ankle for that leg}}{\text{Highest brachial pressure obtained for both arms}}$$

ABPI normally > 1.0

ABPI < 0.92 indicates arterial disease

ABPI > 0.5 and < 0.9 can be associated with claudication and if symptoms warrant a patient should be referred for further assessment

ABPI < 0.5 indicates severe arterial disease and may be associated with gangrene, ischaemic ulceration or rest pain and warrants urgent referral for a vascular opinion

Christian Doppler and the Doppler principle

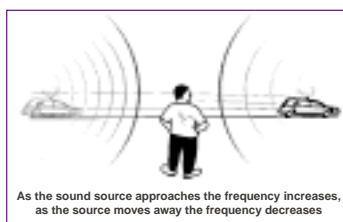
Christian Doppler (1803-1853) was an Austrian professor in Elementary Mathematics and Practical Geometry at the Institute of Physics at Vienna University. A biography describes him as a genius (O'Connor et al, 1998).

Figure 3.
Christian Doppler (1803-1853).

Professor Doppler first presented his work, entitled "On the coloured light of the double stars and certain other stars of the heavens", in Prague on the 25th May 1842. The principle he described, now regarded as the Doppler principle was first published a year later (Doppler, 1843) and relates the frequency of a source to its velocity relative to an observer. This principle was initially not accepted but in 1846 Doppler published the theory again (cited in O'Connor et al., 1998) considering, on this occasion, both the motion of the source and the motion of the observer. At the same time he performed experiments with sound using musicians on a moving train to illustrate his theory. Although his theory was finally accepted equipment was not then available to completely validate it. The most common example of the Doppler principle is a moving siren or train where the frequency of the sound changes as the source approaches (Figure 4). Other applications include a police speed trap!



Figure 4.
The Doppler effect.



Doppler principle in medicine

The first application of the Doppler effect in medicine was made by Satomura in 1957 (cited in Yao, 1970a) who used it to study heart structure and function publishing this work in 1959 (Satomura, 1959). This principle was then extended to examine blood flow in peripheral arteries. Satomura and Kaneko (1960) (cited in Yao, 1970a) giving the first description of a non invasive method of studying blood flow in peripheral arteries in man. Franklin (1961) produced an ultrasonic flow meter based on the Doppler effect from which the now commercially available portable continuous wave Doppler was developed. Strandness et al (1967; 1969) and Sigel et al (1968) used this equipment in patients with peripheral arterial and venous disease, establishing the method of assessment and the pitfalls of the technique.

ABPI and arterial disease

Hamilton et al (1936; cited in Hocken, 1967) established the link between direct and cuff measurement of blood pressure and Winsor (1950) noted the difference between arm and ankle pressures. Prior to the early 1960's it was not routine to measure the blood pressure in the lower limb (Hocken, 1967). Hocken (1966;1967), using a stethoscope and Korotcow sounds, established that it was feasible to measure the blood pressure in the foot but concluded that this was not a satisfactory method for routine practice as the arteries at the ankle do not lend themselves to this technique (Yao, 1993). In these papers Hocken was able to demonstrate an arm leg pressure gradient with leg pressures usually being 20mmHg higher than the arm. One year later Yao et al (1968) reported using ultrasound and the Doppler effect as a new method of recording arterial flow using both the flow velocity patterns and audible

sound. In this study they compared the accuracy of Doppler with pulse palpation noting that in 136 legs in which the pulse could not be palpated, only 14 failed to show a Doppler signal. Yao et al (1969) also demonstrated that Doppler is a reliable and simple method of measuring ankle systolic pressure stating that it should be common practice but comments that it was, at that time, not. Using this technique Yao and others (Sumner, 1989) were able to define what constituted a normal and abnormal pressure index concluding that normal individuals had an ABPI of >1.00 and that patients with arterial stenosis had an ABPI of <1.00. An ABPI of 0.92 is generally regarded as the cut-off for normal (Sumner, 1989).

Doppler, reliability and reproducibility

Hand held continuous wave Doppler ultrasound is considered a reliable tool and was validated and accepted into routine medical practice (Carter, 1969; Yao, 1970a; Yao, 1970b; Strandness et al, 1972; Sumner, 1989). Sumner (1989) when reviewing data obtained after multiple testing of normals and patients with arterial disease concluded that a "normal" ABPI was 1.10 when a well rested subject is lying supine, an ABPI of less than 1.00 was highly suggestive of arterial obstruction. This finding was in agreement with those of his colleagues (Carter, 1969; Yao, 1970b). Sumner (1989) also states that only rarely does a normal limb have an index of less than 0.92 but, as with all biological data, no exact cut-off could be identified. In this way a defined range for normal and abnormal ABPI was established and, through further clinical evaluation, the deficiencies and pitfalls of the technique were recognised.

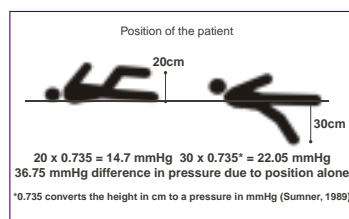
These include:

- Reliance on the arm systolic pressure as the best estimate of central systolic pressure. Carter (1969) and Sumner (1989) comment

that arterial disease can exist in the upper limb. Even in "normals" the pressure in the arms may vary, differences of greater than 15 mmHg indicating aortic arch disease (Carter, 1993). Measuring the pressure in both arms and using the higher of the two pressures increases the non invasive accuracy of measurement of central systolic pressure but will not eliminate this potential flaw in the method. Arterial disease is generalised and may effect all four limbs.

- Influence of patient positioning on the results (Carter, 1993). Lying the patient supine reduces the hydrostatic pressure inaccuracies. Any deviation from the horizontal will require correction for the differences, i.e. the distance that the cuff is above or below the heart. The effect of position can be calculated (Figure 5) and is used in the Pole test to derive ankle pressures (Sumner, 1989; Smith et al, 1994).

Figure 5.
The effect of position on the recording of the ankle systolic pressure



- The need for resting and the effect of exercise. Yao (1970b) observed that up to 25 minutes rest was the time needed for severe multi-level arterial disease patients to recover following exercise. The fall in ankle pressure with exercise can be used to reveal occult arterial disease (Laing et al, 1983) or to assess the severity of symptomatic arterial disease. During stress testing by exercise or hyperaemia (Sumner, 1989; Nicholaides, 1993) the ankle pressure falls and slowly recovers to the pre-exercise level. The time for recovery reflects the severity of the underlying arterial disease (Laing et al., 1983; Carter, 1985)

- Reliability and reproducibility of results over time have been found to vary by 0.06 which is considered acceptable (Sumner, 1989; Carter, 1993). A change in ABPI of 0.15 or more usually implies a significant pathological change (Sumner, 1989).
- Strict requirements for accurate technique including the cuff size, position and probe selection (Carter, 1993; Yao, 1993). The pressure recorded is that at the cuff, not that at the probe and this principle is used when measuring segmental pressures (Sumner, 1989). The importance of cuff size has been recently restated (Beevers et al, 2001), too small a cuff resulting in an over estimate of systolic pressure.
- Variability of pressure between ankle vessels and its relationship to proximal occlusive disease (Carter, 1969; Sumner, 1989). A pressure difference of 15 mmHg between vessels at the ankle indicates proximal disease in the vessel with the lower pressure and may expose the patient to the risk of bandage pressure damage even in the presence of an "acceptable" ABPI of > 0.8.

- Problems encountered with non-compressible vessels (Carter), when assessing subjects with diabetes (Sumner, 1989; Smith et al., 1994). Toe pressures are generally more reliable. The use of the hand-held Doppler in the diabetic has recently been reviewed (Baker et al, 1999; Grasty, 1999; Vowden, 1999). Carter (1969) emphasises that meticulous attention to detail is necessary to obtain valid measurements and a lack of awareness of the limitations of the ABPI leads to conflicting results and misinterpretation of data. When the above factors are taken into consideration the medical literature would indicate that this is a safe and reliable method of monitoring arterial disease. The accuracy of the method along with its limitations have been well researched and continuous wave Doppler is now accepted as routine practice by the medical profession.

Clinical assessment of arterial disease

Doppler assessment and the calculation of the ABPI should not be performed in isolation. Systematic inquiry may reveal underlying risk factors for arterial disease (Vowden et al, 1996b) and there may also be specific symptoms related to lower limb arterial disease such as intermittent claudication or rest pain. There may also be a sudden, rapid, deterioration in a previously asymptomatic leg causing acute limb ischaemia.

Acute arterial occlusion is said to present with the five Ps: pain, pallor, pulselessness, paraesthesia and paralysis. This, however, is not always the case, and the severity and number of symptoms will vary with the level of ischaemia (Rutherford, 1989).

Chronic arterial insufficiency of the lower extremity causes two classic symptoms-intermittent claudication and rest pain (Rutherford, 1989). Claudication is usually described as a cramp-like tightening in the calf, thigh or buttock and occasionally in the foot, brought on by walking a certain distance and relieved by resting, often for several minutes (Marston, 1992).

Rest pain is a different and far more significant symptom. The pain is usually felt in the foot or the toe, often the great toe, and comes on soon after elevating the leg, occurring classically on going to bed. It is usually relieved by hanging the foot out of the bed, and the patient is often forced to sleep in a chair (Marston, 1992).

Other conditions, such as spinal stenosis, can mimic the symptoms of rest pain and intermittent claudication (Marston, 1992). These conditions can often be excluded by physical examination or simple investigations.

Examination of the lower limb

Detailed examination of the legs can give valuable information on the state of the peripheral circulation (Marston, 1992). Gangrene is a strong indicator of arterial disease. The site and appearance of an ulcer can give an indication of its type (Fairbairn, 1972; Negus, 1991; Marston, 1992; Morison, 1992), but the ulcer diagnosis should never be based on appearance alone. Thickening of the nails and slow nail growth is characteristic of chronic arterial insufficiency (Fairbairn, 1972; Rutherford, 1989; Negus, 1991; Marston, 1992), as may be shiny, scaly skin.

Palpation and auscultation of the proximal lower limb pulses can give an indication of the condition of the under-lying vessels (Rutherford, 1989; Marston, 1992; Nicholson et al, 1993). Once the state of the proximal vessels has been assessed and documented, attention should be directed to the ankle and foot pulses. The simple presence or absence of ankle pulses to palpation should not be used alone as an indicator of arterial disease whether assessing the diabetic foot or a patient with a presumed venous leg ulcer. Distal perfusion can only be accurately assessed by the correct application of Doppler or other investigation methods such as photoplethysmography (Whiteley et al, 1998).

ABPI in assessment of leg ulceration

The literature recognises the importance of assessment in the management of a patient with chronic lower limb ulceration (RCN Institute, 1998). Attention is focussed on the role of the ABPI in defining treatment, a ratio of 0.8 being taken as the cut off for the safe introduction of high compression bandaging. This ratio is also taken as the trigger point for

specialist referral in both the Scottish (SIGN, 1998) and RCN (1998) national guidelines on leg ulcer management. What evidence supports this?

The evidence from the medical literature indicates that a "normal" ABPI is 0.92 or greater, a ratio below this indicating arterial disease. Cornwall and colleagues (Cornwall, 1983; Cornwall, 1985b; Cornwall, 1985a) reporting the Harrow experience were the first to suggest the use of Doppler ABPI measurement in the assessment of patients with leg ulceration. These suggestions were supported by Kulozik et al (1986) from Oxford. Cornwall et al (1986) considered that an ulcer occurring in a limb with an ABPI of less than 0.9 should be considered ischaemic and that a pressure index below 0.75 had a significant impact on clinical management. This paper (Cornwall et al., 1986) would appear to be the first reference linking ABPI to compression therapy. Callam et al (1987a; 1987b) reported on the incidence of skin necrosis and amputation due to compression and recognised both the concept of "mixed" ulceration, i.e. venous ulceration in a limb with arterial disease, and the need for reducing the compression levels in patients with an ABPI of 0.7 or less. The authors recognise however that this is a somewhat empirical approach which needs further study. The study as far as the literature shows was not conducted. Blair et al (1988) reported a large venous ulcer study using high compression therapy.

In this seminal paper patients were excluded from receiving high compression bandages when the ABPI was less than 0.8 as this group were felt to be at risk of necrosis from high compression bandaging. No rationale was given as to why 0.8 was used as a cut-off point and yet an ABPI of 0.8 has remained as the pivotal point for compression and referral and has been used in most studies since. These findings were

restated in the nursing literature by Cornwall (1991) where arterial disease was stated to be present when the ABPI is less than 0.9 and it was advised not to apply compression to a limb with a ratio of less than 0.8.

Moffatt et al (1992) reported a large leg ulcer study which involved community clinics where the assessment included an ABPI on 550 ulcerated limbs. Patients with ABPI of less than 0.8 were treated with reduced compression after medical assessment. It is interesting that, as with the earlier reported studies, no particular reason is given as to why 0.8 was chosen and complications from compression bandaging is not specifically mentioned.

Since these initial papers there has been no debate as to why 0.8 is chosen and no questioning regarding this measurement or why a ratio rather than an absolute pressure was chosen as the cut off point for compression therapy. This goes against the literature on pressure sore prevention where work has centred on absolute pressure and its relationship to ulcer occurrence as typified by the original work on capillary closing pressure (Landis, 1931) and the response to loading or pressure on the leg (Sangeorzan et al, 1989).

Segmental pressures

The simple principle of ankle systolic pressure measurement can be extended to allow pressure measurement at other levels along the limb, the pressure relating to the position of the cuff. The use of three or four cuffs placed on the leg each inflated and deflated and in turn the pressure noted allows limb segmental pressure and pressure gradient measurement. This can identify the site of arterial disease by identifying the level at which a greater than expected pressure drop is recorded. The thigh systolic pressure is normally

higher than the brachial and there is normally a pressure gradient down the leg (Hirai et al, 1978).

A gradient of $>30\text{mmHg}$ between adjacent cuffs indicates significant arterial disease (Sumner, 1989).

Toe systolic pressure measurement

Toe systolic pressure measurement and the derived toe brachial pressure index (TBPI) have been suggested as an alternative method of assessment of peripheral vascular disease in the diabetic or patients with medial calcification as it has been demonstrated to be less of a problem in the more distal vessels. Recently Brooks et al (2001) have suggested that this investigation should be reserved for patients with overt evidence of vascular calcification, such as an $\text{ABPI} > 1.3$. Although strain gauge and photoplethysmography are the preferred techniques to measure toe pressure the hand held Doppler can be used (Sumner, 1993). If using the hand-held Doppler a paediatric or penile cuff can be used on the proximal part of the toe, the cuff should be between 2 and 3 cm (Carter, 1993) and flow in the digital artery distal to the cuff identified (Figure 6). Interpretation of the results obtained have been reviewed by Sumner (1989) and Carter (1993). Normally the toe pressure is lower than the ankle and arm pressures (Sumner, 1989), a normal TBPI is > 0.7 and a value of <0.65 would indicate arterial disease (Baker et al., 1999). Low absolute pressures and a reduced TBPI are associated with poor healing of foot ulceration. (Carter, 1993).

Waveforms and Spectral

Hand-Held Doppler Ultrasound:
The assessment of lower arterial and venous disease

Figure 6.
Taking toe pressures with the hand-held Doppler and a penile blood pressure cuff



data

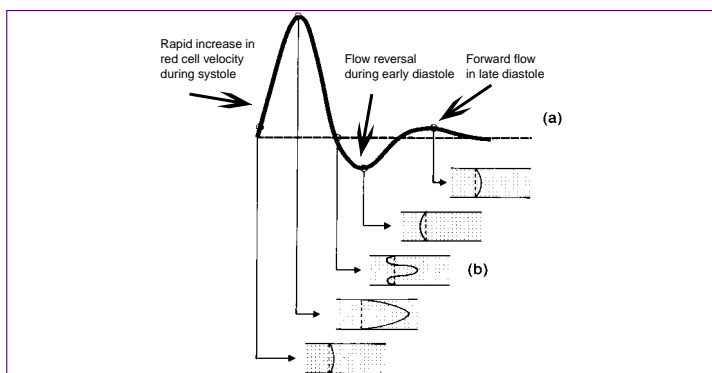
Additional information on the state of the circulation can be derived from signal analysis. In its simplest form this is operator interpretation of the audible signal derived from the hand-held Doppler and skilled observers can derive a great deal of information from this without resorting to complex signal analysis (Sumner, 1989). Alternatively the waveform may be visualised and the Doppler spectrum analysed. The Doppler signal can be displayed on a screen or printer and a waveform generated. The waveform represents red cell velocity changes during the cardiac cycle and the characteristic pattern varies slightly for each artery.

In the lower limb there is a rapid increase in red cell velocity during

systole after which the velocity slows and flow reverses. The elasticity of the vessel generates further forward flow during diastole producing the characteristic triphasic pattern seen in normal lower limb arteries (Figure 7). Increasing stenosis results in progressive dampening of the waveform with loss of reversed flow and the development of a monophasic pattern. Analysis of the waveform can provide a Pulsatility Index (PI) (Figure 8), the lower the PI the greater the degree of proximal stenosis. Details of this method of signal analysis can be found elsewhere (Sumner, 1989; Burns, 1993).

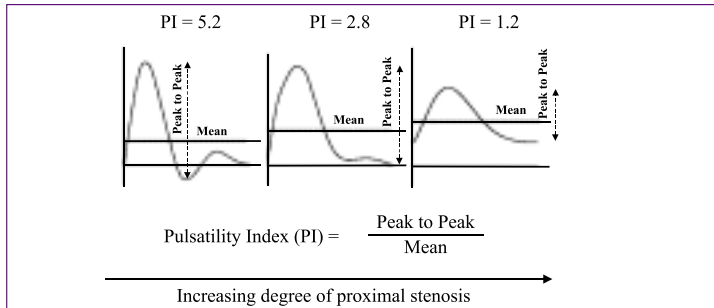
Venous assessment

Figure 7.
The typical appearance of a directional Doppler waveform from a normal common femoral artery (a) showing the flow envelope at various phases of the flow cycle (b)



Kathryn Vowden, Peter Vowden

Figure 8.
How the Pulsatility Index (PI) falls progressively with an increasing degree of proximal stenosis.



An increasing degree of stenosis results in:

1. A slower systolic rise
2. Reduced peak velocity
3. Loss of early diastolic flow reversal
4. A more "rounded" damped waveform

The hand-held Doppler also provides a means by which to carry out a simple assessment of venous reflux and should now form part of the routine assessment of patients with venous disease (Thompson et al, 2001). Some authors have however suggested that duplex ultrasound is necessary in all patients with varicose veins if surgery is considered (Mercer et al, 1998; Jutley et al, 2001). In more complex situations such as recurrent varicose veins, suspected deep vein thrombosis or lower limb venous ulceration, it is more appropriate to assess the patient with other modalities such as colour flow duplex ultrasonography, especially when surgery is considered (Stacey, 2001). When testing for valvular reflux using the hand-held Doppler the patient should stand and the leg to be examined should be relaxed and the knee slightly flexed, the patient's weight being on the opposite leg.

To test for reflux, place the probe over the common femoral or popliteal vein and manually compress and then release the calf muscles. Prolonged audible retrograde flow indicates reflux. By repeating the test after occluding the superficial venous system with direct pressure or a superficial venous tourniquet it is possible to localise the reflux to the deep or superficial systems. Once the junctional areas have been assessed the long and short saphenous veins

should be assessed in a similar way.

Accurate localisation of perforating veins is often not possible with the continuous wave Doppler and it is frequently not possible to define the site of reflux in the popliteal fossa.

Conclusion

The hand-held Doppler has been available for more than 30 years and has been widely adopted as standard equipment for the assessment of peripheral vascular disease for the last 25 years. This versatile, cheap and portable piece of equipment allows the rapid and simple assessment of both arterial and venous disease and with more complex analysis the information obtain can provide a detailed map of both lower limb arterial and venous disease. As a reliable method of assessing the presence, quality and pressure in vessels at the ankle it provides an ideal tool for health care professions wishing to derive information on the aetiology, treatment requirements and the healing potential of wounds on the lower leg and foot. Understanding of the use and limitations of the hand held Doppler should be regarded as mandatory for those concerned with the management of lower limb and foot ulceration in both diabetics and non-diabetics alike.

References

- 1: Baker, N. and Rayman, G. (1999) Clinical evaluation of Doppler signals. *Diabetic Foot* **2** (1 (Supplement)): 22-25.
- 2: Beevers, G., Lip, G. Y. H. and O'Brien, E. (2001) ABC of hypertension: Blood pressure measurement Part 1-Sphygmo-manometry: factors common to all techniques. *BMJ* **322**: 981-985.
- 3: Blair, S. D., Wright, D. D. I., Backhouse, C. D., Riddle, E. and McCollum, C. N. (1988) Sustained compression and healing of chronic venous ulcers. *British Medical Journal* **297**: 1159-1161.
- 4: Brooks, B., Dean, R., Patel, S., Wu, B., Molyneaux, L. and Yue, D. K. (2001) TBI or not TBI: that is the question. Is it better to measure toe pressure than ankle pressure in diabetic patients? *Diabet Med* **18** (7): 528-532.
- 5: Burns, P. N. (1993). Principles of deep Doppler ultrasonography. In: Bernstein, E. F. (ed) *Vascular Diagnosis*, St Louis, Mo.:Mosby.
- 6: Callam, M. J., Harper, D. R., Dale, J. J. and Ruckley, C. V. (1987a) Arterial disease in chronic leg ulceration: an underestimated hazard? Lothian and Forth Valley leg ulcer study. *British Medical Journal Clinical Research Ed.* **294** (6577): 929-931.
- 7: Callam, M. J., Harper, D. R., Dale, J. J., Ruckley, C. V. and Prescott, R. J. (1987b) A controlled trial of weekly ultrasound therapy in chronic leg ulceration. *Lancet* **2** (8552): 204-206.
- 8: Carter, S. A. (1969) Clinical measurement of systolic pressures in limbs with arterial occlusive disease. *Jama* **207** (10): 1869-1874.
- 9: Carter, S. A. (1985). Role of pressure measurements in vascular disease. In: Bernstein, E. F. (ed) *Noninvasive diagnostic techniques in vascular disease*, St Louis, Mo.: Mosby, pp 513-544.
- 10: Carter, S. A. (1993). Role of pressure measurement. In: Bernstein, E. F. (ed) *Vascular diagnosis*, St Louis, Missouri: Mosby, pp 486-512.
- 11: Cornwall, J. (1985a) Diagnosis of leg ulcer. *Journal of District Nursing* **4** (3): 4-6.
- 12: Cornwall, J. (1985b) Treating leg ulcers. *Journal of District Nursing* **4** (4): 4-6, 11.
- 13: Cornwall, J. (1991) Managing venous leg ulcers. *Community Outlook May*: 36-38.
- 14: Cornwall, J. V. (1983) Guidelines to leg ulcer care. *Nursing (Lond)* **2** (11): 317-319.
- 15: Cornwall, J. V., Dore, C. J. and Lewis, J. D. (1986) Leg ulcers: epidemiology and aetiology. *British Journal of Surgery* **73**: 693-696.

Hand-Held Doppler Ultrasound: The assessment of lower arterial and venous disease

- 16:** Doppler, C. (1843) *Über das farbige Lichte der Dopplesterne und einiger anderer Gestirne des Himmels*. Abh. konigl. bohm Ges. Wiss. (Prague) **2**: 465-482.
- 17:** Fairbairn, J. F. (1972). Clinical manifestations of peripheral arterial disease. In: Fairbairn, J. F., Juergens, J. L. and Spittell, J. A. (eds) *Peripheral Vascular Disease*, Philadelphia: W.B. Saunders, .
- 18:** Franklin, D. L., Schlegel, W. A. and Rushmer, R. F. (1961) Blood flow measured by Doppler frequency shift of back-scattered ultrasound. *Science* **134**: 465.
- 19:** Grasty, M. (1999) Use of the hand-held Doppler to detect peripheral vascular disease. *The Diabetic Foot* **2** (1 (Supple.)): 18-21.
- 20:** Hamilton, W. F., Woodbury, R. A. and Harper, H. T. (1936) *Am Med Ass* **107**: 853.
- 21:** Hirai, M. and Shionoya, S. (1978) Segmental blood pressure of the leg and its clinical use. *Jpn J Surg* **8** (2): 102-110.
- 22:** Hocken, A. G. (1966) *Archives of Internal Medicine* **117**: 364.
- 23:** Hocken, A. G. (1967) Measurement of blood-pressure in the leg. *Lancet* **1** (7488): 466-468.
- 24:** Jutley, R. S., Cadle, I. and Cross, K. S. (2001) Preoperative assessment of primary varicose veins: a duplex study of venous incompetence. *Eur J Vasc Endovasc Surg* **21** (4): 370-373.
- 25:** Kulozik, M., Cherry, G. W. and Ryan, T. J. (1986) The importance of measuring the ankle/brachial systolic pressure ratio in the management of leg ulcers. *British Journal of Dermatology* **115**: 26-27.
- 26:** Laing, S. and Greenhalgh, R. (1983) The detection and progression of asymptomatic peripheral arterial disease. *British Journal of Surgery* **70**: 628-630.
- 27:** Landis, E. M. (1931) Micro-injection studies of the capillary blood pressure in human skin. *Heart* **15**: 209-228.
- 28:** Marston, A. (1992). Clinical evaluation of the patient with atheroma. In: Bell, P. R. F.,
- 29:** Jamieson, C.W., Ruckley, C.V. (ed) *Surgical Management of Vascular Disease*, London: W.B. Saunders, .
- 30:** Mercer, K. G., Scott, D. J. and Berridge, D. C. (1998) Preoperative duplex imaging is required before all operations for primary varicose veins. *Br J Surg* **85** (11): 1495-1497.
- 31:** Moffatt, C. J., Franks, P. J., Oldroyd, M., Bosanquet, N., Brown, P., Greenhalgh, R. M. and McCollum, C. N. (1992) Community clinics for leg ulcers and impact on healing. *British Medical Journal* **305** (6866): 1389-1392.
- 32:** Morison, M. J. (1992). *A colour guide to the nursing management of wounds*, London: Wolfe Publishing.
- 33:** Negus, D. (1991). *Leg Ulcers: A practical approach to management*, Oxford: Butterworth Heinemann.
- 34:** Nicholaides, A. N. (1993). Basic and practical aspects of peripheral arterial testing. In: Bernstein, E. F. (ed) *Vascular Diagnosis*, St Louis: Mosby, .
- 35:** Nicholson, M. L., Byrne, R. L., Steele, P. A. and Callum, K. G. (1993) Predictive value of bruit and Doppler pressure measurement in detecting lower limb arterial stenosis. *European Journal of Vascular Surgery* **7**: 59-62.
- 36:** O'Connor, J. J. and Robertson, E. F. (1998). *Christian Andreas Doppler*. School of Mathematics and Statistics, University of St Andrews, Scotland. Available: World Wide Web, Version. Accessed on: 05/12/2000.
- 37:** RCN Institute (1998). *Clinical Practice Guidelines: The management of patients with venous leg ulcers*, London: RCN Institute.
- 38:** Rutherford, R. B. (1989). *The vascular consultation*. In: Rutherford, R. B. (ed) *Vascular Surgery*, Vol. 1. Philadelphia: W.B. Saunders.
- 39:** Sangeorzan, B. J., Harrington, R. M., Wyss, C. R., Czerniecki, J. M. and Matsen, F. A. (1989) Circulatory and mechanical response of skin to loading. *Journal of Orthopaedic Research* **7** (3): 425-431.
- 40:** Satomura, S. (1959) Study of the flow patterns in peripheral arteries by ultrasonics. *J Acoust Soc Jap* **15**: 151.
- 41:** Sigel, B., Popky, G. L., Wagner, D.K, Boland, J. P., Mapp, E. M. and Feigl, P. (1968) Comparison of clinical and Doppler ultrasound evaluation of confirmed lower extremity venous disease. *Surgery* **64** (1): 332-338.
- 42:** SIGN (1998). *The Care of Patients with Chronic Leg Ulcer*, Edinburgh: SIGN Secretariat.
- 43:** Smith, F. C., Shearman, C. P., Simms, M. H. and Gwynn, B. R. (1994) Falsely elevated ankle pressures in severe leg ischaemia: the pole test-an alternative approach. *Eur J Vasc Surg* **8** (4): 408-412.
- 44:** Stacey, M. C. (2001) Investigation and treatment of chronic venous ulcer disease. *ANZ J Surg* **71** (4): 226-229.
- 45:** Strandness, D. E., Jr., Kennedy, J. W., Judge, T. P. and McLeod, F. D. (1969) Transcutaneous directional flow detection: a preliminary report. *Am Heart J* **78** (1): 65-74.
- 46:** Strandness, D. E., Jr., Schultz, R. D., Sumner, D. S. and Rushmer, R. F. (1967) Ultrasonic flow detection. A useful technic in the evaluation of peripheral vascular disease. *Am J Surg* **113** (3): 311-320.
- 47:** Strandness, D. E., Jr. and Sumner, D. S. (1972) Noninvasive methods of studying peripheral arterial function. *J Surg Res* **12** (6): 419-430.
- 48:** Stubbing, N. J., Bailey, P. and Poole, M. (1997) Protocol for accurate assessment of ABPI in patients with leg ulcers. *Journal of Wound Care* **6** (9): 417-418.
- 49:** Sumner, D. S. (1989). Non-invasive assessment of peripheral arterial occlusive disease. In: Rutherford, K. S. (ed) *Vascular Surgery*, Vol. 1. Philadelphia, Pa.: W.B. Saunders, pp 61-111.
- 50:** Sumner, D. S. (1993). Mercury strain-gauge plethysmography. In: Bernstein, E. F. (ed) *Vascular Diagnosis*, St. Louis, Missouri: Mosby,.
- 51:** Thompson, J. F. and Campbell, W. B. (2001) Clinical examination of varicose veins-a validation study. *Ann R Coll Surg Engl* **83** (2): 146-148.
- 52:** Vowden, K. R., Goulding, V. and Vowden, P. (1996a) Hand-held Doppler assessment for peripheral arterial disease. *Journal of Wound Care* **5** (3): 125-128.
- 53:** Vowden, K. R. and Vowden, P. (1996b) Arterial disease: reversible and irreversible risk factors. *Journal of Wound Care* **5** (2): 89-90.
- 54:** Vowden, P. (1999) Doppler ultrasound in the management of the diabetic foot. *Diabetic Foot* **2** (1): 16-17.
- 55:** Whiteley, M. S., Fox, A. D. and Horrocks, M. (1998) Photoplethysmography can replace hand-held Doppler in the measurement of ankle/brachial indices. *Ann R Coll Surg Engl* **80** (2): 96-98.
- 56:** Winsor, T. (1950) Influence of arterial disease on the systolic pressure gradients of the extremities. *Am J Med Sci* **220**: 117.
- 57:** Yao, J. S. T. (1993). Pressure measurement in the extremity. In: Bernstein, E. F. (ed) *Vascular Diagnosis*, St Louis: Mosby, pp 169-175.
- 58:** Yao, S. T. (1970a). Experience with the Doppler ultrasound flow velocity meter in peripheral vascular disease. In: Gillespie, J. A. (ed) *Modern Trends in Vascular Surgery* 1, London: Butterworth, pp 281-309.
- 59:** Yao, S. T. (1970b) Haemodynamic studies in peripheral arterial disease. *Br J Surg* **57** (10): 761-766.
- 60:** Yao, S. T., Hobbs, J. T. and Irvine, W. T. (1968) Pulse examination by an ultrasonic method. *Br Med J* **4** (630): 555-557.
- 61:** Yao, S. T., Hobbs, J. T. and Irvine, W. T. (1969) Ankle systolic pressure measurements in arterial disease affecting the lower extremities. *Br J Surg* **56** (9): 676-679.



HUNTLEIGH HEALTHCARE LIMITED

Diagnostic Products Division

35 Portmanmoor Road, Cardiff,
CF24 5HN, United Kingdom
Tel: +44 (0)29 20485885
Fax: +44 (0)29 20492520
E-mail: sales@huntleigh-diagnostics.co.uk
Website: www.huntleigh-diagnostics.com
Registered No: 942245 England
©Huntleigh Healthcare Limited 2002

® and ™ are trademarks of Huntleigh Technology PLC

As our policy is one of continuous improvement, we reserve the right to modify designs without prior notice.

GENLIT 017/01 LIT 603415-1