(+22%) at the lowest shear rate. The difference in yield stress, which is the minimum force necessary to initiate flow, was even greater, almost 50% (Fig 1). Although these results were obtained using all intermittent claudicants almost two-thirds of them had a viscosity within the normal range and the very high blood viscosities were only found in a third of the cases.

There were a number of differences between patients with intermittent claudication who had a high blood viscosity and those who did not. Many of the patients with abnormally high blood viscosity had a surprisingly normal arteriogram despite severe symptoms of claudication. They also tended to have more severe symptoms; for instance patients with a blood viscosity above 4.5 cP (at a shear rate of 230 s^{-1}) had an average claudication distance of 138 yards (126 m) compared to 316 yards (289 m) for the patients with a blood viscosity below that level. Their prognosis was also different. Those with an initially high blood viscosity had a significantly worse prognosis than claudicants with a normal viscosity.

These results were found in a group of intermittent claudicants who had not received any form of therapy. It is impossible to draw statistically significant conclusions in patients who had undergone reconstructive arterial surgery because of the difficulty of comparing operations. However, patients with a normal blood viscosity and a purely arterial lesion were much better a year after reconstructive surgery than patients with a mixture of arterial narrowing and high blood viscosity.

The basic cause of the high blood viscosity in these patients is now known. It is not due to a difference in hæmatocrit, which is the most critical determinant of viscosity we know. There was, however, a significant correlation between high blood viscosity and plasma fibrinogen (and we believe this to be a far more important biochemical abnormality in patients with circulatory disease than any change in plasma lipid composition).

In summary, we suggest the term 'rheological claudication' to describe those patients with intermittent claudication who have an abnormally high blood viscosity. This is present in approximately 25–30% of all moderate to severe claudicants. In some cases an abnormal blood viscosity may represent the principal etiological factor, while in others it may coexist with some degree of arterial narrowing. We believe it is important to recognize this group of rheological claudicants because their prognosis is significantly worse' and reconstructive surgery is contraindicated. Finally, treatment in these cases should be primarily directed towards correcting their rheological rather than their arterial defect.

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Arterial Assessment by Doppler-shift Ultrasound

It has been shown that Doppler-shifted ultrasound signals can be obtained easily and transcutaneously from many blood vessels in both normal and atherosclerotic subjects (Rushmer *et al.* 1966, Strandness 1969, Kalmanson *et al.* 1968, Gosling *et al.* 1969). Using spectral analysis these Doppler signals present a distribution of frequencies (sonagrams) the envelope of which has a waveform (cardiac period) characteristic of the vessel site in normal subjects (Gosling & King 1974). Disease in the arterial system changes the shape of these 'normal' waveforms. A simple system of quantifying such changes is offered here.

When a specific vessel pathway is defined by using two Doppler probes simultaneously, proximal and distal to the pathway, the sonagrams of both signals can be displayed and read out simultaneously or analysed from tape afterwards (Coghlan *et al.* 1974). Three parameters may be measured from the two simultaneously displayed sonagram waveforms: pulsatility index (PI), damping factor (Δ) and transit time (T). Normal values have been established and departure from these indicates the presence of lesions in the defined pathway (Gosling *et al.* 1971, Fitzgerald *et al.* 1971, Woodcock *et al.* 1972).

Calculation of Key Parameters

Pulsatility index (PI)=(Peak to peak height of sonagram waveform)/(mean height over one cardiac cycle). PI value is therefore independent of probe angle to vessel, carrier frequency and velocity of sound in tissues traversed.

Damping factor (Δ)=(PI proximal)/(PI distal). Like PI, this is independent of probe/vessel factors.

Transit time (T)=(Foot to foot distance between displayed waveforms)/(time base calibration of display). Usually expressed in milliseconds.

Values of Damping Factor and Transit Time in Standard Vessel Pathways

As an example of their use these parameters have been applied here specifically to the diagnosis of lesions in the femoral-popliteal (fem-pop) and the popliteal-posterior tibial (pop-pt) pathways. Values of Δ and T for these pathways in the legs of 28 asymptomatic volunteers in the age range 20–50 years gave mean ± standard deviations of:

Δ fem-pop = 0.79 ± 0.30
T fem-pop = 42.2 ± 4.8 ms
Δ pop-pt = 0.94 ± 0.35
T pop-pt = 40.1 ± 4.6 ms

However, transit time T is a function of the elasticity of the vessel pathway which is dependent on intraluminal pressure and age. A family of T versus pressure curves can be plotted when intraluminal hydrostatic pressure is changed by tilting supine subjects (King *et al.* 1972). Fig 1 is compiled from a study of two groups of asymptomatic subjects between 20–30 years and 50–60 years and represents the mean of 420 data points. Results apply to both standard leg segments. It was found that age differences were consistent but close to the limit of resolution of our method (each measurement being correct to ±4 milliseconds).

Correlation of Ultrasonic Angiology with Radiology

Ultrasonic data were collected from arterial pathways, as defined above, of 33 patients, with clinical signs of peripheral vascular disease who had arteriograms within three days of the ultrasonic examination. This information is displayed in Fig 2 with the lesions as given by the X-ray assessment. Data points for 85 pathways fall into fairly well defined quadrants on this Δ/T graph: (1) Complete block with established collateral (upper right). (2) Severe stenosis (lower right). (3) Vessel severely narrowed over most of pathway (upper left). (4) Patent pathway with no major lesions (lower left). The quadrants are grossly defined by our previously suggested threshold levels of Δ = 1.0 and T = 45 milliseconds on each axis respectively. However, it is clear that uncertainty exists as these thresholds are approached. By normalizing Δ for vessel pathway, T for age and subject's mean blood pressure (1/3 pulse pressure + diastolic) at brachial level for fem-pop segment and knee for pop-pt segment, this uncertainty can be substantially rereduced.

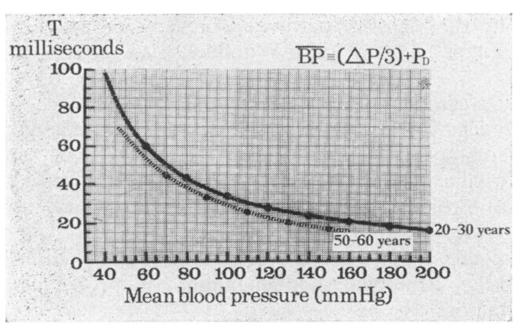

Fig 1 *Variation of time delay with mean pressure in normal patent leg segments. Subject supine. Segment length corrected to 40 cm*

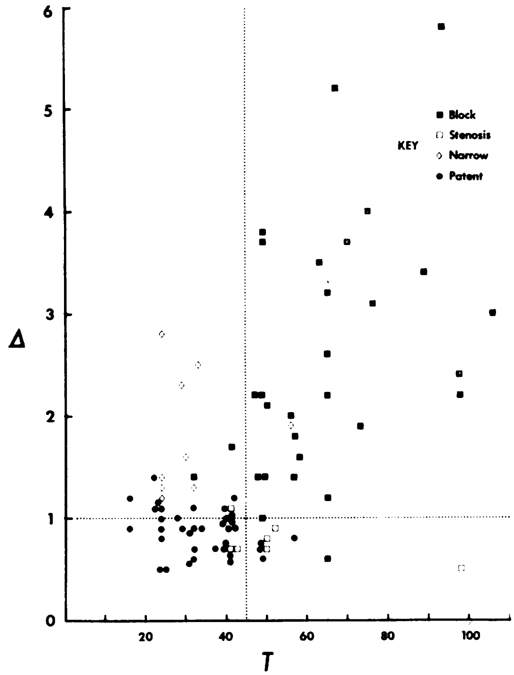

Fig 2 *Values of ultrasonic parameters Δ and T for four vessel conditions diagnosed by X-ray arteriography*

Diagnostic Improvement by Normalization of Δ and T

Definitions:

Δn = (Δ observed)/(Average Δ for same but patent pathway in normals)

Tn = (T observed)/(T for same but patent pathway in comparable age group at subject's blood pressure, as read from Fig 1)

The advantages of normalizing Δ and T are demonstrated in Fig 3. Without normalization (Fig 2) 72% of ultrasound diagnoses would have been correct on a quadrant basis, 4% borderline and 24% incorrect (assuming radiological diagnoses are 100% correct). Using Δ_n and T_n the score becomes 89% correct, 6% borderline and 5% incorrect.

It was notable in this study, due to insufficient angiographic coverage or slow filling of radio-

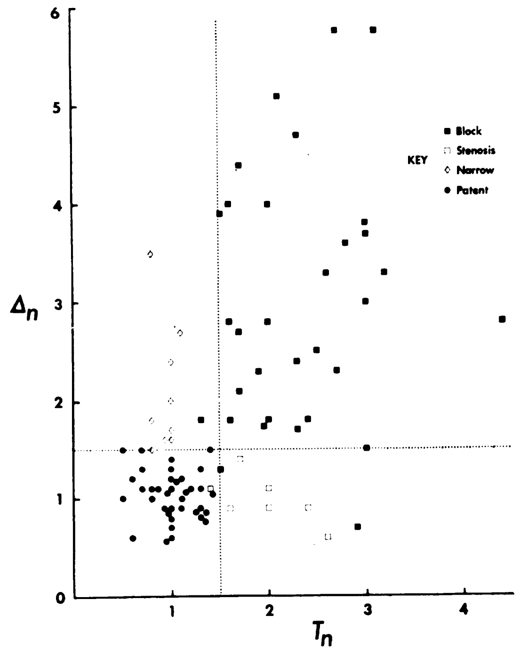

Fig 3 *Normalized parameters Δ_n and T_n give better resolution of vessel conditions, permitting numerate ultrasonic diagnosis*

paque media below a block, that a satisfactory diagnosis of the popliteal – posterior tibial pathway could be made in only 38% of the cases. Using ultrasound a diagnosis could be made in 97% of those examined.

Conclusion

Ultrasonic angiology appears to be a useful complement to arteriography and can provide numerate diagnoses and follow-up of peripheral vascular disease in man.

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Stress Arteriography

Peripheral arteriography is usually performed in the surgical assessment of lower limb ischæmia. To determine the state of intra-abdominal arteries, the quality of the collaterals, and the run off associated with a major vessel lesion, arteriography is essential.

The purpose of stress arteriography (Mackintosh *et al.* 1973) is to improve vessel visualization using a simple, easily applicable technique which will not give artificial results. The essence of the technique is to exercise the affected limb until claudication occurs immediately prior to performing the film run.

Lower limb arteriography is performed under local anæsthesia together with suitable intravenous analgesia by the retrograde femoral or the translumbar route; in the case of the translumbar approach the method of Stocks *et al.* (1969) using a Teflon catheter is the method of choice. When the femoral approach is used the asymptomatic or lesser affected limb is used for the puncture. With the catheter in position the affected limb is exercised; isometric contraction of the quadriceps and contraction of the calf muscles are performed, an assistant applying pressure to the sole of the foot and holding the knee in extension. On occasion the patient is unable to do this and in this instance active exercise of the leg can be employed. This can be done with the patient in the prone or supine position. When ischæmic pain occurs the arteriographic run is performed using automatic table shift and a Siemen's Contrac pressure injector which triggers the X-ray film changer; 35 ml of 70% sodium iothalamate (Conray 420) per injection at a flow rate of 11 ml per second is given.

Various other techniques have been used in an attempt to improve arterial visualization. Drugs such as bradykinin, histamine, acetylcholine, tolazoline, papaverine, lidocaine and procaine have been employed, all with variable and generally poor results. The reactive hyperæmia which follows arterial occlusion by a cuff applied to the limb has been relatively effective but is a cumbersome technique and adds to the discomfort of the procedure. None of these techniques has gained general acceptance and it is submitted that stress arteriography employing simple isometric exercise of the affected limb is a safe, reliable way of improving arterial visualization.