Ultrasound measurements of pulse-wave velocity in the peripheral arteries of diabetic subjects

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Summary

1. Pulse-wave velocity in both upper and lower limbs has been measured in a series of diabetic and control subjects. Subjects were studied with a Doppler ultrasound system and a real-time frequency analyser.

2. The subjects comprised three groups: (a) diabetic subjects with peripheral neuropathy (43); (b) non-complicated diabetic subjects (8); (c) non-diabetic control subjects (11). Those diabetic subjects with peripheral neuropathy included 12 with non-infected foot ulcers, nine with healed foot ulcers and 22 who gave no history of foot ulceration. All of the diabetic and control subjects had clinically normal peripheral pulses.

3. In the upper limbs the pulse-wave velocity was similar for all groups. By contrast, in the lower limbs pulse-wave velocity was significantly increased ($P < 0.005$) in patients with healed or ulcerated feet compared with controls, non-complicated diabetic subjects or diabetic subjects with peripheral neuropathy alone.

4. It is suggested that the increased pulse-wave velocity results from an underlying, diffuse, atherosclerosis. This is not detectable clinically and was found to predominantly affect the lower limb arteries rather than the upper limb vessels. This may be an important aetiological factor in the development of foot ulcers in these patients.

Key words: blood flow, diabetes mellitus, Doppler ultrasound, pulse-wave velocity.

Introduction

The pulse-wave velocity of the pressure and flow waves produced during ventricular ejection has been shown to be a sensitive indicator of the physical properties of the arterial wall (Anliker, Moritz & Ogden, 1968; McDonald, 1974; Greenwald, Newman & Bowden, 1978). Hence, measurements of pulse-wave velocity may be used to determine changes in the condition of the arteries which occur as a result of vascular disease (Woolam, Schnur, Vallbona & Hoff, 1962; Gosling, 1976; Craxford & Chamberlain, 1977).

The true pulse-wave velocity is difficult to determine because of wave dispersion from the frequency-dependent velocities of the wave components and, also, the presence of retrograde waves (Greenwald et al., 1978). The usual technique is to measure the time taken for the 'foot' of the wave to travel over a known distance. The 'foot' is defined as that point at the end of diastole where the waveform begins. This early part of the wave has been found to be little affected by reflections (McDonald & Taylor, 1959; Nichols & McDonald, 1972) and closely relates to the characteristic wave velocity determined by the physical properties of the arterial wall.

Foot ulcers in the diabetic patient are considered to result from occlusive arterial disease, peripheral neuropathy or infection. The last two groups of patients have palpable foot pulses and, in those with infection and hot feet, they may appear to be increased. We have measured the pulse-wave velocity in diabetic subjects with peripheral neuropathy and palpable foot pulses in order to investigate possible sub-clinical peripheral arterial
Patients were studied with, and without, foot ulcers and the pulse-wave velocity was compared in both lower and upper limbs. An ultrasound technique was used to determine the 'foot' of the pulse wave.

Methods

Subjects

Forty-three diabetic subjects with peripheral neuropathy and palpable foot pulses were studied. They all had characteristic symptoms of peripheral neuropathy (paraesthesia, hot and cold sensations in the legs, aching pains, symptoms worse nocturnally) with absent ankle reflexes and sensory impairment. These patients comprised three groups (Table 1). The first group consisted of patients with non-infected foot ulcers, the second of patients with previous foot ulceration, now fully healed, and the third of patients without a history of foot lesions. In addition, eight non-complicated diabetic subjects were also studied together with 11 non-diabetic controls (Table 1). None of the patients, or controls, gave a history of claudication and none was hypertensive. In addition, none had any symptoms of autonomic neuropathy (bladder dysfunction, diabetic diarrhoea, postural hypotension, hypoglycaemic unawareness, abnormal sweating) and all had a normal Valsalva ratio (Levin, 1966). This is probably the most valuable, single, indicator of generalized autonomic dysfunction (Hague, Scarpello, Sladen & Cullen, 1978), although it does not exclude the possibility of localized peripheral autonomic neuropathy.

Procedures

Subjects were studied in the supine position in a warm room (23–25°C). They were connected to an electrocardiograph monitor and, after an initial period of stabilization (30 min), the systolic pressure at the posterior tibial artery in each leg was measured with a sphygmomanometer cuff, placed just above the ankle, and a Doppler ultrasonic probe (Parks 806, 10 MHz) as previously described (Yao, Hobbs & Irvine, 1969). The brachial artery systolic pressure was similarly determined and, hence, the ratio of posterior tibial pressure/brachial artery pressure calculated. If this ratio was less than unity the existence of occlusive arterial disease was assumed (Yao, 1970) and the patients excluded from further study.

A 10 MHz ultrasonic probe was placed over the popliteal artery at the lower boundary of the popliteal fossa. Doppler-shift signals were processed by using a Parks 806 10 MHz Directional Doppler in conjunction with a real-time frequency analyser (Smallwood, Brown & Rodgers, 1977). The frequency-analysed Doppler signals were displayed on a storage oscilloscope. The probe position was adjusted to give the clearest and most reproducible signal free from artifacts caused, for example, by vessel wall movement and venous flow. The frequency-analysed Doppler-shift signals were recorded on a fibre-optic recorder (paper speed, 5 cm/s) to give a tracing as shown in Fig. 1. The density of the tracing indicates the relative amount of blood at a given velocity.

The frequency band just above the end-diastolic flow level was selected from the frequency analyser output and used to generate a trigger-pulse which denoted the onset of flow. The time-delay between the R wave of the electrocardiograph and the onset of flow was electronically calculated on a beat-to-beat basis. The result was digitally displayed as the running average of 10 consecutive cycles. This procedure was repeated with the probe placed over the posterior tibial artery.

Transit times in the leg were calculated by subtracting the time delay from the R wave to the...
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FIG. 1. Frequency-analysed Doppler signals obtained from the posterior tibial arteries in a diabetic patient with an ulcerated right foot (lower record) and an unaffected left foot (upper record).

FIG. 2. Transit time of the flow wave from the popliteal to posterior tibial arteries is found by subtracting the time delay from the R wave to the onset of flow at the popliteal site from that to the posterior tibial artery ($B - A$).

onset of flow at the popliteal site from that to the posterior tibial artery, as shown in Fig. 2. Similarly, transit times were calculated from the brachial to radial arteries. The pulse-wave velocity was calculated by dividing the exteriorly measured distance between the pulse sites (cm) by the average time difference.

Results were compared by using Student's $t$-test. Significance was considered to have been achieved at the 5% level.

Results

A typical recording of the blood velocity waveform found in a patient with an ulcer of the right foot is shown in the lower record of Fig. 1. For
Table 2. Pulse-wave velocities measured in the upper and lower limbs related to patient groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower limb</th>
<th>Upper limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-diabetic</td>
<td>11.5 ± 0.5</td>
<td>12.9 ± 1.2</td>
</tr>
<tr>
<td>Non-complicated diabetic</td>
<td>11.0 ± 0.5</td>
<td>12.2 ± 1.0</td>
</tr>
<tr>
<td>Diabetic, with neuropathy but no ulcers</td>
<td>12.1 ± 0.4</td>
<td>12.3 ± 0.9</td>
</tr>
<tr>
<td>Diabetic, with neuropathy and active ulcers</td>
<td>14.2 ± 0.8***</td>
<td>13.1 ± 2.0</td>
</tr>
<tr>
<td>affected</td>
<td>14.6 ± 0.7***</td>
<td></td>
</tr>
<tr>
<td>unaffected</td>
<td>15.7 ± 1.5***</td>
<td></td>
</tr>
<tr>
<td>Diabetic, with neuropathy and healed ulcers</td>
<td>15.1 ± 1.0***</td>
<td></td>
</tr>
<tr>
<td>affected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unaffected</td>
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</tbody>
</table>

***P < 0.005.

comparison, the normal appearance of the tracing obtained from the unaffected left foot is shown above.

The pulse-wave velocities for both upper and lower limbs are shown in Table 2. In the upper limb no significant differences were found between non-diabetic controls and any of the other groups, or between the non-complicated diabetic patients and all three groups were peripheral neuropathy. By contrast, in the lower limbs the pulse-wave velocity in patients with past, or present, foot ulcers was significantly greater (P < 0.005) than in non-diabetic controls, non-complicated diabetic subjects or the non-affected peripheral neuropathy group. There was no statistical difference between affected and unaffected limbs in the two groups with foot-lesions.

The mean diastolic blood pressure was similar for all groups (Table 1).

Discussion

Pulse-wave velocity is determined primarily by the elasticity of the arterial wall (Gosling, 1976), although several factors may affect it, including the diastolic blood pressure, arterial wall thickness, blood density and blood flow velocity (Woolam et al., 1962). As stated above, the mean diastolic blood pressure of each of the groups in this study was similar. However, the presence of a steady flow found in all of the patients with foot ulcers will increase the wave velocity by the amount of the stream velocity. Thus, if the characteristic wave velocity is Co and the flow velocity \( V \), then the flow wave will travel at a velocity \( C \) downstream such that \( C = Co + V \) (McDonald, 1974).

The maximum Doppler-shift frequency found during the diastolic flow period was 2 kHz. If the angle of the probe to the vessel is assumed to be 45° then the flow velocity calculated from the Doppler equation (Gosling, 1976) is 0.2 m/s. This value is less than 3% of the lowest pulse-wave velocity found. Thus the effect is minimal and need not be considered an important determinant of the pulse-wave velocity. Therefore the increase in pulse-wave velocity found in the lower limbs of the patients with healed, or active, foot lesions most probably results from a change in arterial wall elasticity. The high pulse-wave velocity therefore probably indicates incipient atherosclerosis. Since the pulse-wave velocity was not increased in diabetic patients in whom there was no history of foot ulceration, this suggests that underlying atherosclerosis, while clinically undetectable, may be an important aetiological factor in the development of foot ulceration.

By contrast, in the upper limbs the pulse-wave velocity appears similar in all groups, including the non-diabetic controls. These results differ from an earlier series in which, by using external transducers rather than ultrasound, the pulse-wave velocity was found to be increased in diabetic compared with healthy control subjects (Woolam et al., 1962), although no measurements were made in the lower limbs for comparison. Similarly, there are several reports of increased pulse-wave velocity in diabetic children (Katz, Cheitlin, Wasser & Flair, 1971; Pillsbury, Hung, Kyle & Freis, 1974). However, Gosling (1976) has criticized these findings in view of the wide age ranges of patients and controls. In his own study (Gosling, 1976) of aortic compliance in juvenile-onset diabetes in patients examined within 1 year of diagnosis he reported increased, rather than decreased, compliance and suggested that this may produce changes in arterial wall permeability resulting in
Atherosclerosis. In the only previous study using ultrasound, Cairns, Woodcock & Marshall (1978) reported increased arterial wall stiffness in the lower limbs of maturity-type diabetic subjects compared with controls.

There is, thus, some discrepancy in the literature concerning pulse-wave velocity and arterial compliance in diabetic subjects. The present findings would appear to confirm that changes in pulse-wave velocity, and hence arterial wall elasticity, occur in some, but not all, diabetic patients of similar clinical history. Perhaps the very much higher incidence of ulceration in diabetic feet compared with the hands reflects, at least partially, increased atherosclerotic degeneration in the lower limb arteries compared with the upper limb vessels as indicated by the increased pulse-wave velocity in these subjects.

References


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