Diabetologia (1982) 22: 9–15

Diabetologia

Blood Flow in the Diabetic Neuropathic Foot

M. E. Edmonds, V. C. Roberts and P. J. Watkins

Diabetic Department and Department of Biomedical Engineering, King's College Hospital, London, UK

Summary. The mechanisms which underlie the development of Charcot joints and foot ulceration are poorly understood. The present study using non-invasive Doppler techniques demonstrates that in the neuropathic leg, the arteries are rigid, peripheral blood flow is increased and associated with arteriovenous shunting. We studied 10 diabetics with severe neuropathy (including five with Charcot changes), 16 diabetics without neuropathy and 10 control subjects. Markedly abnormal blood velocity profiles (sonograms) were demonstrated only in those patients with severe neuropathy. They showed increased diastolic flow (indicated by a reduced Pulsatility Index of 2.88 ± 0.8 (mean ± SD) compared with 9.53 ± 4.0 ($p < 0.001$) in the diabetics without neuropathy and 10.8 ± 3.7 ($p < 0.001$) in the control subjects) suggesting arteriovenous shunting. Increased rigidity was indicated by decreased transit times –57 ± 6.3 ms (mean ± SD) in the diabetics with neuropathy compared with 66 ± 7.6 ms ($p < 0.01$) in the diabetics without neuropathy and 67 ± 9.1 ms ($p < 0.05$) in the control subjects. This was accompanied by raised ankle systolic pressures –199 ± 22 mmHg (mean ± SD) in the diabetics with neuropathy compared with 151 ± 15 mmHg, ($p < 0.001$) in the diabetics without neuropathy and 146 ± 18 mmHg ($p < 0.001$) in the control subjects. Medial wall calcification occurred almost exclusively in the neuropathic subjects. These alterations in blood flow which include arteriovenous shunting may be important in the pathogenesis of complications of the neuropathic leg.

Key words: Blood flow, diabetic neuropathy, neuropathic ulcer, Charcot joint, transit time, Doppler technique.

Blood flow in the ischaemic limb has been extensively investigated in the last 15 years but the circulation of the limb affected by peripheral neuropathy has received little attention. This particularly applies to diabetes mellitus, the commonest cause of peripheral neuropathy in the Western World. The importance of neuropathy in the pathogenesis of foot lesions has been widely recognised in diabetes since the report of Oakley et al. in 1956 [1]. Often there is no evidence of peripheral arterial disease but the neuropathy may lead to disturbance in blood flow which may be important in the aetiology of the lesions which we associate with neuropathy, namely the neuropathic ulcer and the neuropathic joint.

The few studies of blood flow in peripheral neuropathy which have been undertaken have shown a markedly increased resting flow as demonstrated by venous occlusion plethysmography, with loss of the normally occurring spontaneous variations which depend on sympathetic activity [2–5]. Arteriograms have shown increased vascularity with rapid flow through the dilated vessels of the feet and early filling of the venous circulation [6, 7]. The possibility of abnormal arteriovenous shunting was suggested to explain these features.

The aim of the present study was to discover the extent and nature of this blood flow abnormality, together with its possible consequences, in diabetics with severe neuropathy often extreme enough to have caused ulceration or arthropathy, using modern Doppler techniques.

Subjects and Methods

Thirty-six subjects were studied and these were divided into three groups. The first group, the neuropathic subjects, comprised 10 insulin-dependent diabetics with peripheral neuropathy sufficiently

012-186X/82/0022/0009/$01.40

Table 1. Clinical details of the subjects with neuropathy

Patient	Sex	Age (years)	Duration of diabetes (years)	Beat to beat score	Neuropathic complications	Retinopathy	Albuminuria (Albustix)
1	M	35	28	3	Ulcer Charcot	Proliferative	+
2	F	42	21	3	Ulcer Charcot	Proliferative	++
3	M	32	20	8	Ulcer	Background	Trace
4	F	51	21	2	Ulcer[a]	Proliferative	0
5	F	44	25	2	Ulcer[a]	Proliferative	++
6	F	46	30	1	Ulcer[a]	Background	0
7	M	52	41	2	Charcot	Proliferative	++
8	F	52	27	3	Ulcer[a]	Background	+
9	M	44	26	5	Charcot	Proliferative	++
10	M	26	16	9	Ulcer[a] Charcot	Proliferative	+

[a] = Healed at time of examination

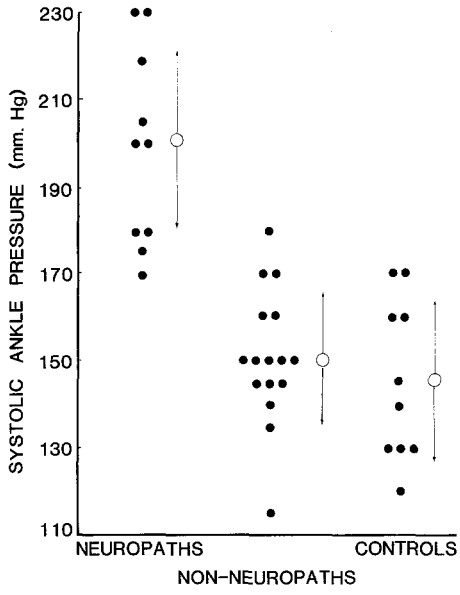

Fig. 1. Systolic ankle pressures (with open circles and arrows representing mean ± SD) in the neuropathic subjects, the subjects without neuropathy (non-neuropaths) and the control subjects

severe to cause neuropathic ulcers, Charcot arthropathy or both. Ankle jerks at least were absent and sensation impaired in every case. They all had evidence of autonomic neuropathy with a grossly abnormal beat-to-beat score (which represents the difference in heart rate between maximal inspiration and expiration) of less than 10 [8]. Mean age was 42.4 years (range 26–52 years), and mean duration of diabetes was 25.5 years. There were five males and five females. The frequency and severity of other complications are shown in Table 1.

The second group consisted of 16 insulin-dependent diabetics with no evidence of neuropathy, i. e. the ankle reflexes were present and autonomic function tests were normal. Mean age was 41.6 years (range 24–52 years) and the mean duration of diabetes was 23.8 years. There were nine males and seven females.

The third group, the control subjects, consisted of 10 normal subjects with no evidence of neuropathy. Mean age was 40.8 years (range 30–52 years). There were four males and six females.

Four investigations were carried out: 1) measurement of resting brachial, ankle and toe systolic pressures; 2) recording of blood velocity profiles (sonograms); 3) measurement of transit time from the femoral to the posterior tibial artery; these investigations were performed under standardised conditions: the subjects rested supine for 20 min at a controlled temperature of 21 °C before observations were taken; and 4) soft tissue X-rays of the feet and ankles were taken in the diabetic groups.

Systolic Pressures

Brachial pressure was measured with a standard 12 cm cuff using Doppler ultrasound kinetoarteriography. Measurements were taken at 2-min intervals for 10 min on each arm and the mean calculated. Ankle pressure was measured using a sphygmomanometer cuff (12 cm diameter) applied just above the ankle. A 10 MHz continuous wave Doppler probe was placed over the posterior tibial artery and the cuff inflated. During deflation, a return of flow signals indicated the level of systolic pressure. Three readings were taken on each foot and the mean calculated. Toe pressure was recorded in a similar way. A 2-cm digital cuff was used and pressure recorded from the second toe with the Doppler probe insonating the digital artery on the medial side. Three readings were taken bilaterally and the mean calculated.

The pressure index was calculated as the ratio of ankle systolic to brachial systolic pressure. The ratio of the systolic toe to systolic brachial pressure, i. e. the toe-brachial pressure ratio, was also calculated. The ankle-toe gradient, i. e. the difference between ankle and toe pressure for each foot, was also derived.

Sonograms

Sonograms were recorded from the femoral, posterior tibial and dorsalis pedis arteries bilaterally using 10 MHz continuous wave Doppler probe. Pulsatility index was calculated as $\frac{\text{peak to peak height}}{\text{mean area}}$ [9]. The pulsatility index was expressed as the mean of readings from 10 consecutive waveforms for each foot.

Transit Times

Blood velocity profiles were recorded simultaneously from the femoral and posterior tibial arteries. The pulse time delay, i. e. the time for the pulse wave to travel from the femoral to the posterior

Table 2. Mean ankle-brachial ratio, toe-brachial ratio and ankle-toe gradient in neuropathic subjects compared with subjects without neuropathy and control subjects (results expressed as mean ± SD showing significances of difference from the neuropathic subjects)

	Neuropathic subjects	Subjects without neuropathy	Control subjects
Ankle-brachial pressure ratio	1.45 ± 0.13	1.16 ± 0.11 $p < 0.01$	1.09 ± 0.08 $p < 0.01$
Toe-brachial pressure ratio	1.06 ± 0.22	0.88 ± 0.12 $p < 0.05$	0.91 ± 0.1 $p < 0.05$
Ankle-toe gradient (mmHg)	53.9 ± 27	37.2 ± 16 $p < 0.05$	23.5 ± 9.5 $p < 0.05$

tibial artery, was calculated and expressed as the transit time. Recordings were taken from the foot of each waveform of the sonogram using a Hewlett Packard 9820 programmable calculator interfaced to a 9864 digitising platten. The mean was calculated from seven cycles. The surface distance from the femoral artery to the posterior tibial artery was measured for each leg and the pulse wave velocity calculated. The pulse wave velocity is related to the elastic properties of the arteries of the leg by the formula: pulse wave velocity = $(K/_Q)^{1/2}$, where Q is the density of the blood, taken as 1050 kg^{-3}, and K the volume distensibility elastic modulus of the artery wall per unit length of vessel [10]. K was then calculated.

X-rays

Soft tissue X-rays of the feet and ankles were taken in the diabetic groups to assess the frequency of medial wall (linear) calcification both in the proximal part of the foot, namely the ankle and metatarsal regions, and the distal part, i. e. the digital arteries.

Presentation of Results

All values are presented as mean ± standard deviation and statistical analysis of results was by the Student's 't' test.

Results

Pressure Studies

The mean brachial systolic pressure was similar in the three groups: 138 ± 14 mmHg in the diabetics with neuropathy, 131 ± 15 mmHg in the diabetics without neuropathy and 135 ± 18 mmHg in the control subjects. The mean ankle systolic pressure was significantly raised in the neuropathic subjects, 199 ± 22 compared with 151 ± 15 mmHg, $p < 0.001$, in the diabetics without neuropathy and 146 ± 18 mmHg, $p < 0.001$, in the control subjects. The mean toe systolic pressure was similarly raised. It was 144 ± 23 mmHg in the neuropathic subjects compared with 114 ± 13 mmHg, $p < 0.001$, in the non-neuropathic subjects and 122 ± 17 mmHg, $p < 0.01$, in the control subjects. The distribution of the mean systolic ankle pressures for each subject is shown in Figure 1.

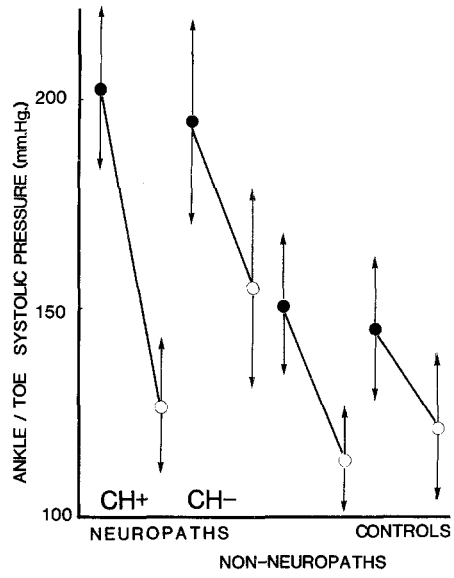

Fig. 2. Mean ankle pressures (closed circles) and toe pressures (open circles) with arrows representing mean ± SD, showing mean ankle-toe gradients in the four groups. In the neuropathic subjects with Charcot joints (CH+) this was 76.4 ± 15.5 mmHg compared with 40.8 ± 23 mmHg ($p < 0.001$) in neuropathic subjects without Charcot joints, (CH −) 37.2 ± 16 mmHg ($p < 0.001$) in diabetics without neuropathy and 23.5 ± 9.5 mmHg ($p < 0.001$) in the control subjects

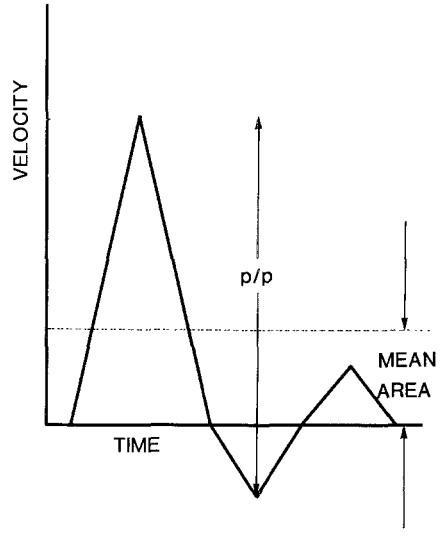

Fig. 3. Diagrammatic representation of normal blood velocity profile with triphasic pattern.

$$\text{Pulsatility index} = \frac{\text{peak to peak height}}{\text{mean area}} \text{ (p/p)}$$

When the ankle and toe systolic pressures for each subject were compared to the corresponding brachial pressure, the ankle-brachial and toe-brachial pressure ratios so derived were significantly elevated in the neuropathic subjects (Table 2). These ratios were cal-

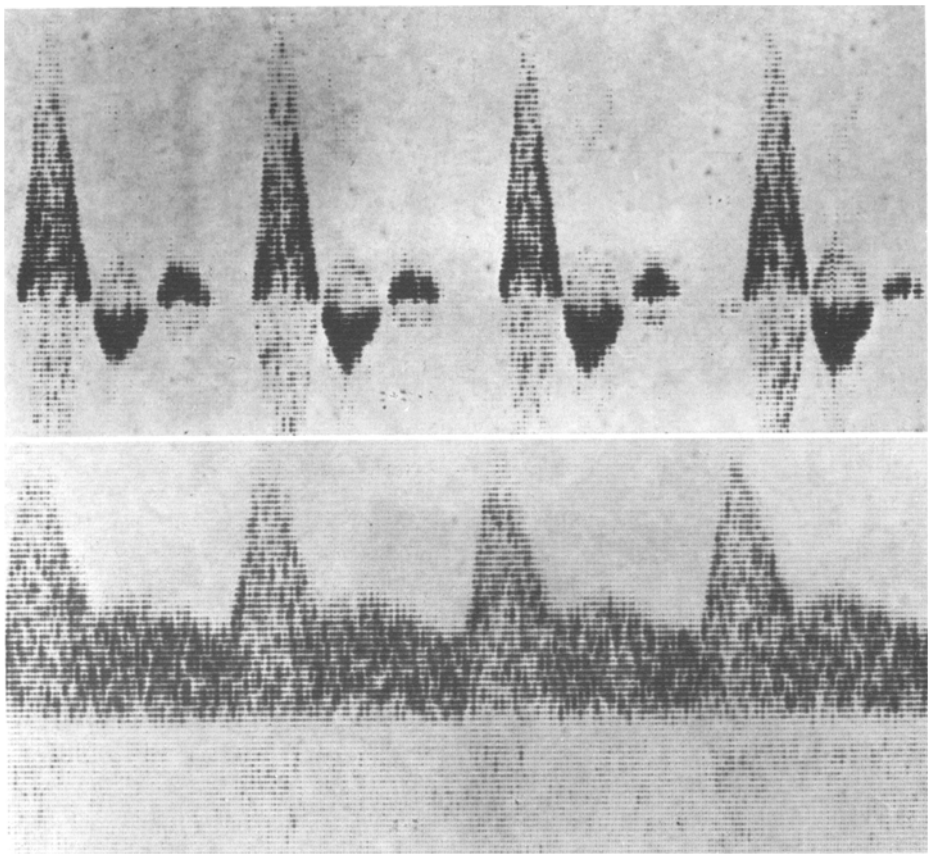

Fig. 4. Sonograms from dorsalis pedis artery of a control subject (above) and a neuropathic subject with Charcot joint (below)

culated to take into account possible individual variations in brachial pressure.

The fall in pressure from the ankle to toe was greater in the neuropathic subjects compared with the controls (Table 2). The drop in pressure was especially marked in those neuropathic subjects with Charcot joints (Fig. 2). These subjects thus had lower toe pressures than those neuropaths without Charcot joints with a correspondingly reduced mean toe-brachial pressure ratio of 0.87 ± 0.10 compared with 1.18 ± 0.21, $p < 0.001$, in the diabetics with neuropathy, but without Charcot joints.

Sonograms

The normal blood velocity profile is triphasic in pattern (Fig. 3). There is an initial forward flow in systole denoted by a positive upward deflection followed by a short reversed flow shown by the negative deflection and a further forward flow in diastole again showed by a positive deflection. The pulsatility index = $\frac{\text{peak to peak height}}{\text{mean area}}$ [9] (Fig. 3). The mean area is considerably influenced by diastolic flow such that the pulsatility index is inversely related to diastolic flow.

Femoral Pulse Sonograms

The typical triphasic pattern was obtained in all three groups. The mean pulsatility index was similar in the three groups: 8.92 ± 3.87 in the neuropathic subjects, 8.98 ± 3.08 in the subjects without neuropathy and 9.14 ± 3.42 in the control subjects.

Pedal Pulse Sonograms

The subjects without neuropathy and the control subjects showed the characteristic triphasic pattern (Fig. 4). The neuropathic subjects showed absence of reverse flow and prolonged diastolic flow. Those subjects with neuropathic joints showed markedly abnormal traces with continuous forward flow throughout the cycle (Fig. 4). The mean pulsatility index was significantly reduced in the neuropathic subjects, 2.88 ± 0.8, compared with 9.53 ± 4.0, $p < 0.001$, in the subjects without neuropathy and 10.8 ± 3.7, $p < 0.001$, in the control subjects (Fig. 5). This indicates increased

diastolic flow in the neuropathic subjects. Those subjects with neuropathic joints had a considerably reduced mean pulsatility index of 1.89 ± 0.58 compared with 3.34 ± 0.90, $p < 0.001$, in the remaining neuropathic subjects.

Transit Time Studies

The transit time of the pulse wave velocity was reduced in the neuropathic subjects (57 ± 6.3 ms) compared with the subjects without neuropathy (66 ± 7.6 ms, $p < 0.01$) and the control subjects (67 ± 9.1 ms, $p < 0.05$). This indicated that the arteries of the neuropathic subjects were stiff and this was confirmed by the increased elastic modulus and pulse wave velocity (Table 3).

X-Rays

Medial calcification in the ankle and metatarsal regions was present in eight of the ten neuropathic subjects compared with three of the 16 diabetics without neuropathy. Calcification in the digital vessels of the foot was uncommon and similar in the two groups, occurring in two of the ten neuropathic subjects and one of the 16 diabetics without neuropathy.

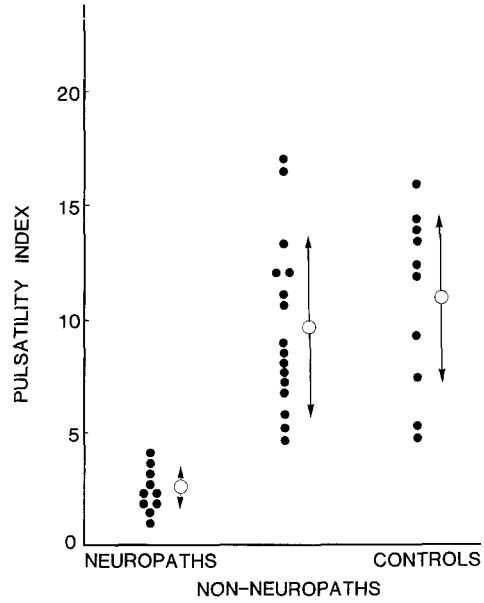

Fig. 5. Pulsatility index (with open circles and arrows representing mean ± SD) in the neuropathic subjects, the subjects without neuropathy (non-neuropaths) and the control subjects

Table 3. Mean pulse wave velocity and elastic modulus in the neuropathic subjects compared with subjects without neuropathy and conctrol subjects (results expressed as mean ± SD showing significances of difference from the neuropathic subjects)

	Neuropathic subjects	Subjects without neuropathy	Control subjects
Pulse wave velocity (m/s)	13.13 ± 0.94	11.54 ± 1.23 $p < 0.01$	11.34 ± 1.45 $p < 0.01$
Elastic modulus (Newton $m^{-2} \times 10^5$)	1.80 ± 0.30	1.41 ± 0.27 $p < 0.01$	1.37 ± 0.32 $p < 0.01$

Discussion

The peripheral arteries in the neuropathic limb of the diabetic were stiff as shown by the pressure and transit time studies, and there was a marked increase in peripheral blood flow associated with arteriovenous shunting.

The sonograms of the pedal pulses in the neuropathic subjects showed marked forward diastolic flow and absence of reversed flow as indicated by the reduced pulsatility index. Forward arterial flow in diastole is normally negligible in the resting limb. Decreased resistance eliminates reversed flow and increases forward flow during diastole. This phenomenon has been described in the hyperaemia associated with exercise, the relief of ischaemia, vasodilator drugs as well as with arteriovenous shunting [11]. In the absence of these other factors the sonograms which represent reduced peripheral resistance and vasodilatation were compatible with arteriovenous shunting. Arteriovenous anastomoses are particularly prominent in the skin of the lower limb but also occur in bone, joint and muscle [12]. They have a rich innervation which is primarily under the control of the sympathetic system although digital arteriovenous anastomoses also possess a cholinergic innervation [13]. Thermally induced reflex changes in skin blood flow are mediated via sympathetic nervous action on the arteriovenous anastomoses [14] and one would expect arteriovenous shunts to open following sympathetic denervation.

There is evidence to support the concept of significant arteriovenous shunting in the neuropathic limb. In 1957 Bureau described the rapid appearance of small opaque streaks as "des images de communications arterioveineuses" in the foot in femoral arteriograms of neuropaths [6] although this impression is not universally accepted [15]. There is a reduced arteriovenous oxygen saturation difference in the neuropathic limb [16] and Boulton et al. reported a significantly raised venous pO_2 of 59.9 mmHg in diabetics with neuropathy severe enough to cause ulceration compared to a pO_2 of 45.5 mmHg in control subjects [17]. Also Partsch has demonstrated an increased arteriovenous shunt volume in the neuropathic limb

using radioactive labelled human albumin microspheres [2]. Situations analogous to autonomic neuropathy have also been examined for the presence of arteriovenous shunting. After sympathectomy in the dog arteriovenous shunt volume increased from 3.8% to 32.1% [18]. Phentolamine, the α-adrenergic blocker, produced similar results.

Thus in severe neuropathy it is likely that significant arteriovenous shunting does occur. Nelms has shown that a shunt dilated to an inner diameter of 60 μ may permit 1000 times as much blood to pass through it than when its size is 10 μ [19]. Arteriovenous shunting could have two effects. The capillary circulation may be short circuited and thus the effective nutrient flow reduced. However in the sympathectomised dog, although arteriovenous anastomotic flow increased from 4 to 54 ml/min, capillary flow was unchanged [18]. Secondly Luckner has shown that when arteriovenous anastomoses are open there is a rise in venous pressure which spreads to the capillary bed, raising capillary pressure [20]. This would partially account for the oedema often seen in diabetic neuropathy [21].

The arterial pressures at the ankle and toe were significantly raised in the neuropathic subjects. Raised ankle systolic pressures could represent increased arterial wall stiffness, correlating with changes in the tunica media of the artery such as calcification [22]. Our radiological studies of the feet and ankle (more proximal views were not taken in this study) showed that calcification was much more common in the neuropathic subjects compared with the control subjects. Thus in the neuropathic subjects a possible explanation of the raised ankle pressure was increased arterial wall stiffness due to medial wall calcification.

Further evidence to support increased arterial wall stiffness came from the transit time studies, which showed the transit times to be significantly reduced in the neuropathic subjects with a resultant increase in the pulse wave velocity. The elastic modulus, a further indicator of stiffness, was also increased. Previous studies have reported increased pulse wave velocity and elastic modulus in the arteries of the lower limbs of diabetics [9, 10] but only one study was confined specifically to neuropathic subjects. Scarpello et al. found the pulse wave velocity to be increased in the lower limbs of severe neuropathic subjects [23].

A further possible explanation for the raised ankle systolic pressure involves the contribution of smooth muscle to the functional behaviour of the larger arteries. Vasodilatation itself can lead to increased stiffness [24]. There was indeed evidence of marked vasodilatation in the peripheral arteries and this may have influenced both the pressure and transit time readings. However, Gosling could demonstrate no significant alteration in stiffness in the upper limb after cervical sympathectomy [9] and on balance we conclude that medial wall calcification was probably the most important factor in the elevation of ankle systolic pressure in the neuropathic subjects.

The mean toe systolic pressure was also raised in the neuropathic subjects compared with the control subjects. However the mean toe pressure was lower than the ankle pressure in all three groups studied. The mean fall in pressure from ankle to toe (the ankle-toe gradient) was greater in the neuropaths and this was particularly marked in those subjects with neuropathic joints (Fig. 2). This may be explained by the marked peripheral vasodilatation and associated arteriovenous shunting in these subjects. In normal subjects vasodilatation causes a drop in pressure from ankle to toe [25]. There have been very few reports of toe pressure measurements in peripheral neuropathy. Variable effects of sympathectomy have been reported by others who have shown both a reduction [26] and an increase in toe pressures [27]. Faris attributed a reduction in toe pressure to peripheral small vessel disease in his neuropathic subjects [28] but this is unlikely to be the explanation in our neuropathic subjects as their mean toe pressure was greater than that of the control subjects.

What is the relationship of these abnormalities in blood flow to the characteristic lesions of the neuropathic foot? Blood flow was abnormal in all the neuropathic subjects even in those limbs without such lesions but those with neuropathic joints were notable for increased diastolic flow as well as a sharp decrease in pressure from ankle to toe. This suggests that together with the loss of the protective effect of pain, abnormality of flow may be an important aetiological factor in the neuropathic joint. Arteriovenous shunting leading to increased venous pressure may lead to abnormal bone cell activity and eventual rarefaction of bone [29]. The foot is then more susceptible to abnormal mechanical stresses that occur in the neuropathic foot with eventual development of the neuropathic joint.

If indeed abnormalities of flow are responsible for lesions in the neuropathic foot, what can be done to influence them? Lefaucher reported ligating the dorsalis pedis artery with resolution of ulcers in the neuropathic foot [30]. Ergotamine, an α-adrenergic agonist, may in theory be useful and has been shown to reduce flow through other arteriovenous anastomosies, namely those in the cranial circulation of the cat [31]. However much more research into this problem is needed before one could consider such drastic measures in the treatment of the diabetic foot.

Acknowledgements. We are grateful for the helpful advice of Mr. G. Wilton of the Department of Biomedical Engineering and to Dr. D. A. Pyke for his great interest. M. E. E. was supported by the King's College Hospital Voluntary Research Trust; we would also like to thank Mr. P. A. Bailey, technician, who was supported by a grant from the British Diabetic Association.

References

1. Oakley WG, Catterall RCF, Martin MM (1956) Aetiology and management of lesions of the feet in diabetes. Br Med J 2: 953–957
2. Partsch H (1977) Neuropathies of the ulceromutilating types. Clinical aspects, classification, circulation measurements. Vasa 6 (Suppl): 1–48
3. Partsch H (1978) Vascular regulation disorders in ulcerative and mutilating neuropathies of the lower extremities. Vasa 7: 119–125
4. Christensen NJ (1969) Spontaneous variations in resting blood flow, post-ischaemic peak flow and vibratory perception in the feet of diabetics. Diabetologia 5: 171–178
5. Sknitizsky R (1977) Spontaneous rhythm of peripheral blood supply. Z Gesamte Inn Med 32: 310–313
6. Bureau Y, Barrière H, Kerneis J-P, De Ferron A (1957) Acropathies ulcéro-mutilantes pseudosyringomyeliques non familiales des membres inférieurs. Presse Méd 65: 2127–2132
7. Seignon B, Menonteau B, Hibon J, Gougeon J (1974) Acropathie ulcéro-mutilante et arthropathie du diabète sucre. II Étude artériographique. Revue du Rhumatisme 41: 341–347
8. Wheeler T, Watkins PJ (1973) Cardiac denervation in diabetes. Br Med J 4: 584–586
9. Gosling RG (1977) Extraction of physiological information from spectrum-analysed Doppler-shifted continuous wave ultrasound signals obtained non-invasively from the arterial system. In: Hill DW, Watson BW (eds) IEE Medical electronics monographs 18–22. Peter Peregrinus, Stevenage, pp 73–125
10. Cairns SA, Woodcock JP, Marshall AJ (1978) Early arterial lesions in maturity onset diabetes mellitus detected by ultrasonic technique. Diabetologia 14: 107–111
11. Rutherford RB, Fleming PW, McLeod FD (1978) Vascular diagnostic methods for evaluating patients with arteriovenous fistulas. In: Diethrich EB (ed) Non-invasive cardiovascular diagnosis. Current concepts; University Park Press, Baltimore, pp 217–230
12. Sherman JL (1963) Normal arteriovenous anastomoses. Medicine (Baltimore) 42: 247–267
13. Mescon H, Hurley HJ, Moretti G (1956) The anatomy and histochemistry of the arteriovenous anastomoses in human digital skin. J Invest Dermatol 27: 133–145
14. Hales JRS, Iriki M, Tsuchiya K, Kozawa E (1978) Thermally induced cutaneous sympathetic activity related to blood flow through capillaries and arteriovenous anastomoses. Pflügers Arch 375: 17–24
15. Garusi GF (1968) Étude artériographique du pied chez le subjet normal. J Radiol Electrol 49: 15–28
16. Bazex A, Montastruc P, Bazex J, Zemb J-P (1975) Acropathie ulcéro-mutilante. Bull Soc Fr Syphiligr 82: 288–290
17. Boulton AJM, Scarpello JHB, Ward JD (1980) Venous oxygenation in the diabetic neuropathic foot. Diabetologia 19: 558–559
18. Cronewatt JL, Lindenauer SM (1977) Direct measurement of arteriovenous anastomotic blood flow after lumbar sympathectomy. Surgery 82: 82–89
19. Nelms JD (1963) Functional anatomy of skin related to temperature regulation. Fed Proc 22: 933–936
20. Luckner H (1955) Die Funktionen der arterio-venosen anastomosen. In: Bartelheimer H, Kuchmeister H (eds) Kapillaren und Interstitium. Georg Thieme Verlag, Stuttgart, pp 78–90
21. Rundles W (1945) Diabetic neuropathy. Medicine (Baltimore) 24: 111–160
22. Podhaisky H, Amthor A, Hänsgen K, Preu BEG, Sternitzky R (1979) Doppler-sonographische Befunde bei röntgenologisch objektivierter Mediasklerose im Extremitätenbereich. Z Gesamte Inn Med Ihre Grenzgeb 34: 213–216
23. Scarpello JH, Martin TR, Ward JD (1980) Ultrasound measurements of pulse wave velocity in the peripheral arteries of diabetic subjects. Clin Sci Mol Med 58: 53–57
24. Gow BS (1970) Viscoelastic properties of conduit arteries. Circ Res 26, 27 (Suppl II): 113–122
25. Carter SA (1978) Effect of age, cardiovascular disease and vasomotor changes on transmission of arterial pressure waves through the lower extremities. Angiology 29: 601–616
26. Nielsen PE, Bell G, Augustenborg G, Paaske-Hansen O, Lassen NA (1973) Reduction in distal blood pressure by sympathetic nerve block in patients with occlusive arterial disease. Cardiovasc Res 7: 577–584
27. Strandness DE Jr, Bell JW (1964) Critical evaluation of the results of lumbar sympathectomy. Ann Surg 160: 1021–1029
28. Faris I. Small and large vessel disease in the development of foot lesions in diabetics (1975) Diabetologia 11: 249–253
29. Hungerford DS (1975) Early diagnosis of ischaemic necrosis of the femoral head. Johns Hopkins Med J 137: 270–275
30. Lefaucher C, Bardoux J, Fréneaux B (1975) La désarterialisation pédieuse dans le traitement des troubles trophiques de l'acropathie ulcéro-mutilante. Nouvelle Presse Med 4: 2325–2326
31. Spierings EGH, Saxena PR (1979) Effect of ergotamine on cranial arteriovenous shuntings in experiments with constant flow perfusion. Eur J Pharmacol 56: 31–37

Received: 27 February 1981
and in revised form: 29 June 1981

M. E. Edmonds
Diabetic Department
King's College Hospital
Denmark Hill
London SE5 9RS, UK