Pulse Pressure Wave Analysis in the Diagnosis of Aorto-iliac Disease

S. H. LEVESON, P. J. GUILLOU, H. J. TERRY, J. N. GLANVILLE, R. C. KESTER

The severity of aorto-iliac disease has been evaluated by direct pressure recording at the time of translumbar aortography. Pulse wave analysis confirmed the radiological appearance of 35 aorto-iliac segments and in one further segment, identified a normal haemodynamic pattern in the presence of marked degenerative disease. The method is safe, accurate, simple and relatively inexpensive.

Departments of Surgery and Radiology,
St. James's University Hospital,
Leeds, England

OCCLUSIVE ARTERIAL DISEASE involving the aorto-iliac and femoropopliteal segments is largely evaluated by the clinical history, appearance of the lower limbs, palpation of leg pulses and single-plane arteriography.

Since experienced observers may differ on the significance and interpretation of such clinical findings, a decision to reconstruct a diseased femoropopiteal segment in the presence of occult but significant aorto-iliac disease may lead to early postoperative failure.[4] In addition, symptoms may originate from unrecognized aorto-iliac obstruction, which as the sole lesion, may not be identifiable by the standard radiological technique of single-plane arteriography.

This paper describes our assessment of the physiological influence of atheromatous disease of the aorto-iliac segment on the form of its pulse wave, by direct pressure measurement at the time of translumbar aortography. In addition, we have compared a method of evaluating the aorto-iliac pressure wave with the degree of radiological disease.

Patients and Methods

Both lower limbs of 18 patients presenting with intermittent claudication were studied. There were 12 men and 6 women aged 47–76 years with a mean of 59.6 years. Eleven patients had unilateral claudication and seven had bilateral claudication. All were to have translumbar aortography performed as part of the investigation of their disease, with a view to arterial reconstruction.

Following informed consent, pressure in the aorta and both common femoral arteries was measured at the time of aortography. All patients were admitted to hospital on the day before aortography. They were premedicated with Diazepam 10 mg, and Pentazocine 50 mg given intravenously 15–20 minutes before aortography, and they were observed in the ward for 24 hours following the procedure.

Technique

The equipment for pressure measurement consisted of a strain gauge pressure transducer (Elcomatic, Ltd.) connected to a heated stylus chart recorder (Devices, Ltd.). The pressure transducer was coupled to the needle used for arterial puncture by a manometer connecting tube (Vygon Sterile) 1.5 m long. The calibration of equipment was checked against a mercury manometer before and after use. The dynamic response of the system, including the needle and connecting tube, was checked by means of a variable frequency pressure generator. It was found that the response was level (±3dB) over the range 0–10 Hz. The patient's brachial artery pressure was measured using a sphygmomanometer before and after the procedure.

Following the injection of contrast material (Conray 310) into the aorta with the patient prone, the manometer tube was flushed with sterile heparinized saline and connected to the translumbar needle. Arterial pressure was recorded for about 30–60 seconds immediately following injection of contrast at a chart speed of 25 mm S^{-1}. After removal of the translumbar needle, the patient was turned into the supine position, the manometer tube was flushed and connected to a 19 gauge needle inserted into each femoral artery in turn, and the pressure at each site was recorded. When no femoral pulse was palpable, the artery was located by a Doppler ultrasonic flow detector (Parks Electronics

Reprint requests: S. H. Leveson, % Department of Surgery, St. James Hospital, Leeds 9, Yorkshire, England.
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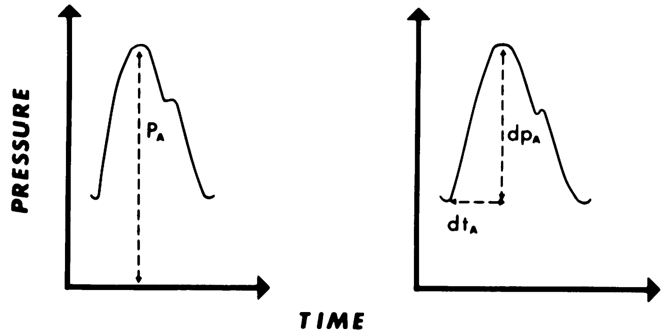

FIG. 1. Analysis of pulse wave-form measuring peak systolic pressure and systolic slope.

Lab.). The additional time taken for the pressure measurements was no more than 15 minutes. No complication as a result of arterial puncture was observed, and no change in systemic blood pressure was noted in any patient.

Analysis of the Pressure Waveform

In the absence of significant arterial obstruction, the pressure waveform in the aorta resembles that in the common femoral artery and has the general appearance as in Figure 1. The effect of a stenosis or occlusion between the two sites of measurement is to attenuate the higher frequencies present in the femoral waveform, reducing the rate of rise of the systolic pressure pulse (dP/dt) and reducing the systolic pressure, P, compared with the aortic waveform.[5,15]

We analyzed the pressure waveforms for each limb in two ways:

1. Pressure Index $\left(\frac{\text{Systolic Femoral Pressure}}{\text{Systolic Aortic Pressure}} = \frac{{}^{p}F}{{}^{p}A}\right)$

2. Systolic Slope Index $\left(\frac{\text{Femoral Systolic Slope}}{\text{Aortic Systolic Slope}} = \frac{{}^{dp}F}{{}^{dt}F} \cdot \frac{{}^{dt}A}{{}^{dp}A}\right)$

One would expect both indices to exceed unity in the absence of obstruction and to be reduced as the severity of the aorto-iliac obstruction increased. Three waveforms were chosen at random from each pressure tracing and mean pressure and systolic slope indices for each aorto-iliac segment were calculated.

Results

The results of 19 limbs with extensive aorto-iliac disease on single-plane arteriography were compared with those 17 limbs where arteriography demonstrated little or no disease of the aorto-iliac segment (Fig. 2). Firstly, when examining the peak systolic pressure indices obtained for the 36 segments, the pressure indices for the abnormal segments were generally lower than those observed in the normal segments but there was a considerable overlap between the two groups.

On the other hand, with but one exception, all the slope indices obtained for extensively diseased aorto-iliac segments were below a level of 0.6, while those of normal or minimally-diseased segments were well above this level with no overlap between the two groups. The one exception was a patient who had extensive disease of both aorto-iliac segments (Fig. 3) with a correspondingly low pressure index (0.79) and slope index (0.53) on the right side. The pressure index on the left was 0.89 with a slope index of 0.88. This patient underwent bilateral aorto-iliac endarterectomy,

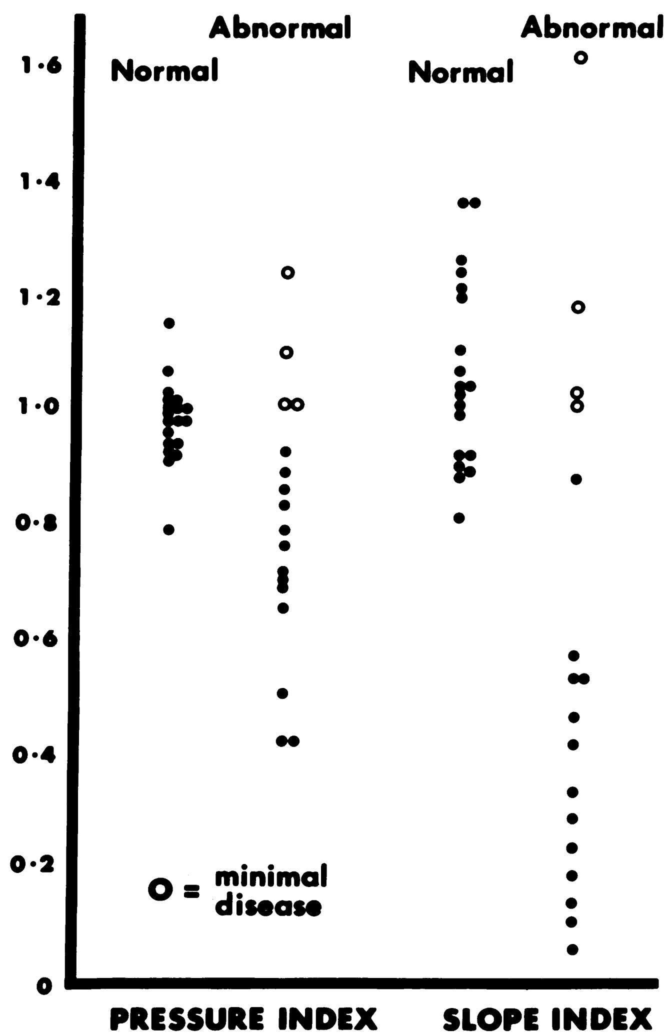

FIG. 2. Arteriogram. Peak systolic pressure and systolic slope indices measured in 36 aorto-iliac segments.

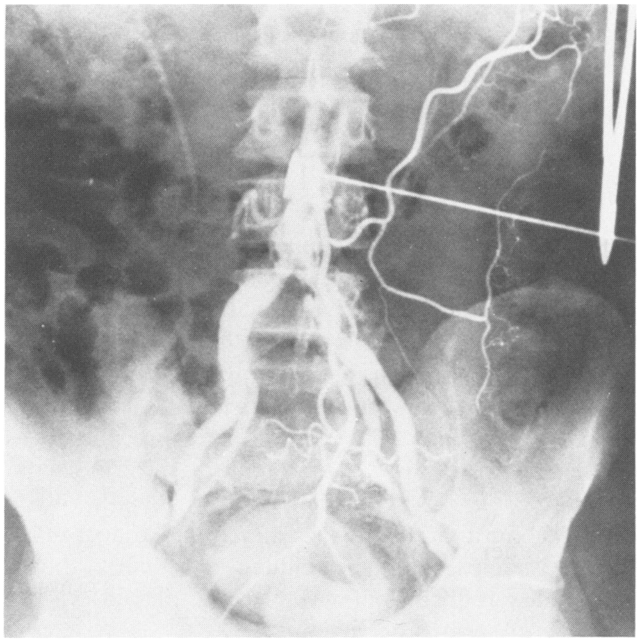

FIG. 3. Aortogram showing bilateral common iliac artery stenosis.

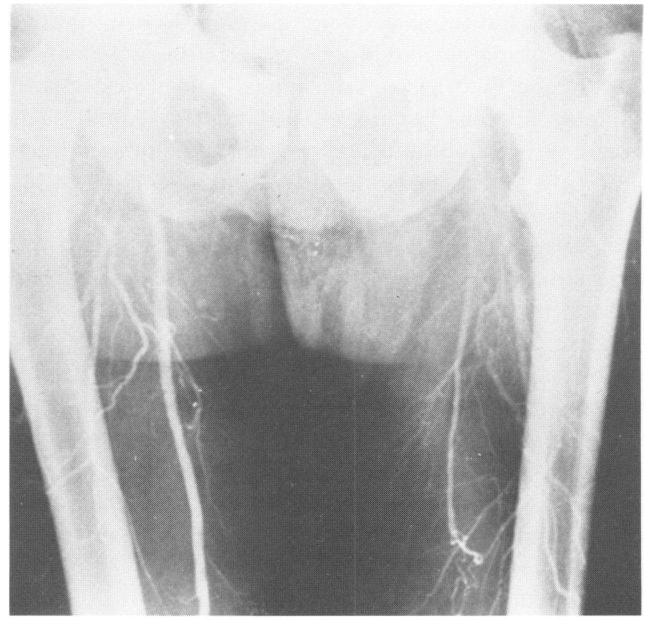

FIG. 4. Left femoropopliteal occlusion.

which, although relieving his right-sided claudication, had no effect on the symptoms from his left leg. The predominant vascular lesion on this side proved to be the femoropopliteal occlusion shown in subsequent films (Fig. 4). In addition to this, all the patients with low slope indices who subsequently underwent aorto-iliac disobliterative or reconstructive surgery were cured of their symptoms. The three remaining patients who had radiographically abnormal aorto-iliac segments in the presence of normal pressure wave analyses had complete femoropopliteal occlusions. Surgery was performed on these effected segments with relief of symptoms in these patients. Hence, it can be seen that the presence of a low slope index would appear to be a more sensitive indicator of the aorto-iliac stenosis than would the presence of a low pressure index.

When the results of the peak systolic pressure indices and slope indices for the 36 aorto-iliac segments were compared (Fig. 5) there was found to be a highly significant correlation between the two parameters, with $r = 0.81$ and $p < 0.05$.

Discussion

When a patient with intermittent claudication is assessed with a view to vascular reconstruction, single-plane arteriography is a standard procedure of the investigation. Although arteriography is valuable in displaying the character and distribution of aorto-iliac occlusive disease, nevertheless, aortography has limitations in gauging the significance of such stenosis.[14] Firstly, since the aortogram is usually taken in the posteroanterior plane, a large intraluminal projection on the anterior or posterior wall may well be obscured by overlying contrast medium. Secondly, aortography gives little indication about impaired haemodynamics when the visco-elastic or flow properties of the aorto-iliac segment are altered. In order to obtain multiplane views during arteriography, expensive and sophisticated apparatus is required which is not available in every radiological department.

Several haemodynamic methods of assessing the

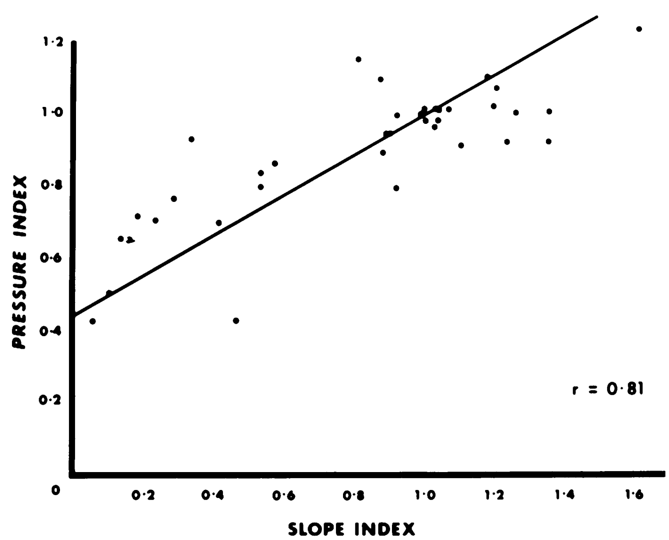

FIG. 5. Correlation between pressure and systolic slope indices for 36 aorto-iliac segments.

aorto-iliac segment have been evolved, which complement the limitations of single-plane aortography. Pressure gradients and blood flow have been measured in stenosed iliac arteries in anaesthetised dogs[12] and isolated human aorto-iliac segments removed at necropsy.[17] Moore and Hall[14] made a valuable contribution by recording bilateral femoral artery pressures simultaneously by direct needle puncture before and after exercise in 45 patients. Of 28 patients with no apparent radiological iliac stenosis, 17 had an abnormal femoral pressure drop of a mean 9 mm Hg following exercise. All 17 patients were found to have significant aorto-iliac disease at operation. Furthermore, Brener et al.[3] also assessed aorto-iliac disease by direct pressure recording in 73 patients at the time of transfemoral arteriography. They confirmed the presence of serious proximal occlusion in 22 patients by demonstrating a fall of 10–40% of the femoral systolic pressure during reactive hyperemia. Two patients with gross radiological changes underwent needless aorto-iliac reconstruction despite evidence from the pressure measurements that the offending occlusion was more distal.

Another method of assessing blood flow through the aorto-iliac segment is on the operating table at the time of reconstruction, by open measurements of the common femoral artery pressure before and after intra-arterial injection of papaverine, a vasodilator. Barner et al.[1] and Quin et al.[16] were able to identify those patients with significant aorto-iliac stenosis following distal vasodilation.

The Doppler principle has been used to evaluate the aorto-iliac segment by analyzing the velocity waveform in the femoral artery,[4,9] but such practice is not universal because of the cost and complexity of the apparatus. Thigh pressure measurement with the Doppler probe is not sensitive enough to distinguish between aorto-iliac and femoropopliteal disease, while examination of the femoral artery flow profile does not permit a confident diagnosis in every patient.[6] Various analyses of the arterial pressure waveform have been made[2,8,10,11,19,20] which gauge the extent of arterial disease, but these methods too, require complicated equipment.

When measuring arterial blood pressure by invasive means, the preparation of the hydraulic system for transmitting intra-arterial pressure to a manometer is crucial in order to avoid distortion of the recorded pulse wave.[7] Although we were reasonably satisfied that our system was quite precise by testing it with a pressure generator, we did not find the aorto-femoral pressure index—using peak systolic pressure—sufficiently sensitive to discriminate between the intermediate degrees of aorto-iliac disease and the normal segments. Since pressure measurements are most meaningful when flow through the aorto-iliac segment is maximal,[1,13,16] we are now evaluating the effect of hyperaemia of the legs on the aorto-femoral pressure and slope indices using this method, following occlusion of the thigh arteries with a cuff.

As the pressure pulse wave travels from the heart to the periphery, its amplitude (or pulse pressure) increases and the rate at which the leading edge rises, is increased, leading to a steeper front.[17] In this study we have chosen to examine the character of the leading edge of the pulse waveform. We have measured the mean rate of change during the rising phase of the aortic pressure pulse following left ventricular ejection, expressed as dpA/dtA. The femoral pressure pulse was likewise measured and an aorto-femoral slope index obtained, ${}^{dp}F/{}^{dt}F \cdot {}^{dt}A/{}^{dp}A$ which is >1 in health. When there was an appreciable resistance in the aorto-iliac segment, such as stenosis, hidden or obvious, then a slope index reduced below 0.6 easily picked out the presence of serious occlusion.

We believe that our method of analysis of the pulse waveform in the aorta and femoral arteries adds a dynamic quantitative assessment to the findings of standard aortography. An immediate evaluation, particularly supported by the value of the slope index, can be made of the significance of aorto-iliac disease, so leading to a more accurate and confident diagnosis. Such hemodynamic assessment not only supports the arteriographic findings of gross disease, but forestalls unnecessary reconstruction of disease, which, although obvious in the arteriogram, proves to be of little haemodynamic significance. Furthermore, such an assessment is made well in advance of the operation, giving the surgeon ample time to plan definitive management of aorto-iliac disease. The procedure was safe in that no complication following femoral artery puncture was observed. No extra expense was entailed, as the equipment we had recourse to, is available in most well-equipped general hospitals. We conclude that direct pressure recording of the aorta and femoral artery, combined with waveform analysis, is a useful adjunct to uniplane aortography and it is a reasonably simple and accurate means of assessing the significance of aorto-iliac occlusive disease.

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