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Assessment of Stenoses in the Aortoiliac Tract by Calculation of a Vascular Resistance Change Ratio Before and After Exercise

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Objectives: *Intraarterial pressure measurement is the most reliable method to assess haemodynamically significant stenoses in the aortoiliac tract. We have tried to develop a simple and quick, non-invasive method to assess stenoses of this type.*

Design: *Prospective semi-blinded clinical study.*

Methods: *It was postulated that a haemodynamically significant aortoiliac tract stenosis would result in a lesser degree of vascular resistance decrease after vasodilatation, compared to patients only suffering from femorodistal stenoses. We approximated vascular resistance by: (brachial pressure–ankle pressure) / femoral artery mean Doppler velocity. By dividing vascular resistance at rest by vascular resistance after exercise, we calculated the Resistance Change Ratio (RCR).*

Patients and results: *In 34 patients (50 legs) with arterial stenoses, the pressure gradient over the aortoiliac segment was compared to the RCR. Legs were divided in three groups: group 1 consisted of 22 legs that showed a pressure gradient > 10 mmHg at rest; group 2 showed a pressure gradient > 10 mmHg after papaverine; group 3 showed a pressure gradient of 10 mmHg or less. The median RCR was: 0.74 (range: 0.23–4.04) for group 1, 0.71 (range: 0.36–1.80) for group 2 and 0.93 (range 0.36–2.06) for group 3. There was no significant difference between the groups* ($p = 0.19$).

Conclusion: *The RCR could not be used to accurately detect stenoses in the aortoiliac.*

Introduction

Before peripheral vascular reconstruction is performed, it is essential to distinguish between femorodistal occlusive disease alone and combined aortoiliac and distal occlusive disease; the patency of peripheral bypasses is adversely influenced if haemodynamically significant upstream stenoses are left untreated. Intraarterial aortofemoral pressure measurements are considered to be the gold standard for identifying aortoiliac stenoses.[1] Obviously the main disadvantage of intraarterial pressure measurements is its invasive character. The colour Duplex scanner offers the possibility of non-invasive investigation of these vessels. However Duplex scanning of the entire aortoiliac segment is time-consuming and operator dependent.

The aim of this study was to devise and evaluate a simple non-invasive investigation of the aortoiliac tract, using a combination of Duplex scanning of the common femoral artery and the ankle-brachial index measured at rest and after peripheral vasodilatation.

Our measurement methods were based on the following concept: after peripheral vasodilatation, flow in the common femoral artery and the aortodistal pressure gradient will both increase in the same proportion if a stenosis is located in the aortoiliac tract. However if a stenosis is located in the femorodistal tract, the flow in the common femoral artery will increase further after peripheral vasodilatation, because it 'includes' the flow increase through patent deep femoral artery.

By using Ohm's law: '$V = I \times R$', which can be translated as: '*resistance = pressure gradient / flow*', one can calculate the vascular resistance of the leg. The pressure gradient was approximated by subtracting the ankle systolic pressure from the brachial systolic pressure and the flow was approximated by measuring the mean blood flow velocity in the common femoral artery with a colour Duplex scanner (see Fig. 1). The vascular resistance measurement was performed before and 1 min after a 5 min treadmill exercise. By dividing the vascular resistance at rest by

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the vascular resistance after exercise induced vasodilatation, the Resistance Change Ratio (RCR) was calculated.

To evaluate the possible clinical value of the RCR, a prospective study, comparing this non-invasively obtained value with the current gold standard: intra-arterial pressure measurement, was performed.

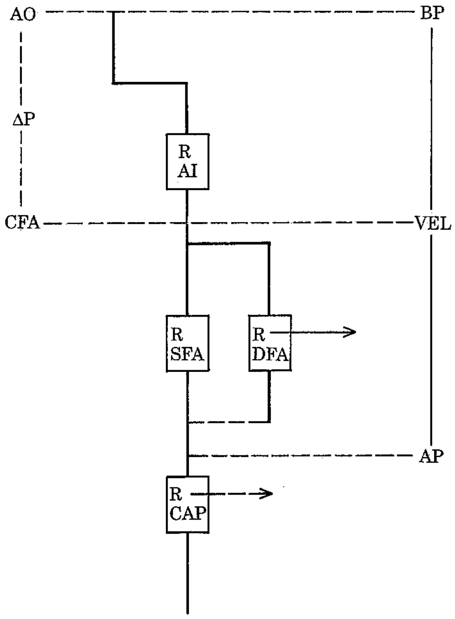
Patients and Methods

Fifty legs were evaluated in 34 patients (16 men, 18 women) with severe intermittent claudication or critical ischaemia. Only legs with a patent deep femoral artery were entered into the study. A colour Duplex scanner (Philips Quantum, U.S.A.) was used to measure the mean velocity (VEL) in the common femoral artery at rest ('rest' measurements) and 1 min after a maximum of 5 min treadmill walk ('stress' measurements; treadmill speed: 4 km/h, or less if this was too fast for the patient). At the same time the ankle and brachial systolic pressures (AP and BP) were measured (see Fig. 1) using a pressure cuff and Doppler flow meter (Vasoflo 2, Sonicaid Ltd., U.K.). The RCR was then calculated:

$$\mathrm{RCR} = \frac{(\mathrm{BP}\mathit{rest}-\mathrm{AP}\mathit{rest})\ /\mathrm{VEL}\mathit{rest}}{(\mathrm{BP}\mathit{stress}-\mathrm{AP}\mathit{stress})\ /\mathrm{VEL}\mathit{stress}}$$

A Seldinger angiogram and intraarterial pressure measurements in the aorta and the femoral arteries were simultaneously performed. The investigators measuring the intraarterial pressure gradients were unaware of the results of the non-invasive measurements and vice-versa. The aortofemoral pressure gradient was calculated by subtracting systolic femoral artery pressure from systolic aortic pressure before and after injection of 25 mg papaverine into the femoral artery. We considered a pressure gradient of more than 10 mmHg without papaverine administration an indication of a haemodynamically significant aortoiliac stenosis.[2] A pressure gradient of more than 10 mmHg after injection of 25 mg papaverine was considered a mild aortoiliac stenosis. A pressure gradient of 10 mmHg or less after papaverine injection ruled out a haemodynamically significant aortoiliac stenosis.

After the intraarterial pressure measurements, the legs were divided into three groups with significant, mild or no haemodynamically significant aortoiliac stenoses: (1) pressure gradient > 10 mmHg in rest; (2) pressure gradient > 10 mmHg only after papaverine; (3) pressure gradient ≤ 10 mmHg. The Kruskal-Wallis test was used to test for a statistical difference in RCR values between the pressure gradient groups.



R = (BP-AP)/VEL
RCR = R*rest*/R*stress*

Fig. 1. Schematic drawing of the arteries supplying a leg, the resistances and the measurements. AO = aorta; CFA = common femoral artery; ΔP = intra-arterial pressure difference; R AI = aorto-iliac resistance; R SFA = superficial femoral artery resistance; R DFA = deep femoral artery resistance (variable); R CAP = capillary and arteriolar resistance (variable in patients only suffering intermittent claudication, fixed in patients suffering critical ischaemia); BP = brachial pressure; VEL = mean blood flow velocity in the common femoral artery; AP = ankle pressure. The Resistance Change Ratio (RCR) is calculated from the resistance (R) in rest (R*rest*) and after a treadmill walk (R*stress*).

Results

Intraarterial aortofemoral pressure measurements showed the following results: in 22 legs a pressure gradient of more than 10 mmHg at rest was found (group 1); eight legs showed a pressure gradient of more than 10 mmHg after injection of 25 mg of papaverine (group 2) and 20 legs showed a pressure gradient of 10 mmHg or less at rest and after papaverine injection (group 3). Figure 2 shows the results of the RCRs for the three groups. The median RCR in group 1 was: 0.74 (range: 0.23–4.04); in group 2: 0.71 (range 0.36–1.80) and group 3: 0.93 (range: 0.36–2.06). In nine of the 22 legs in group 1, the pressure gradient was more than 30 mmHg at rest. The median RCR in this subgroup was: 0.87 (range: 0.34–2.62). There was no significant difference between the groups.

Discussion

Several authors have suggested methods for non-invasive assessment of haemodynamically significant stenoses in the aortoiliac segment. An extensively reviewed measurement is the pulsatility index proposed by Gosling *et al.*[3] One of the advantages, especially when measured with a single continuous wave Doppler probe, is that this value is independent of the Doppler probe-to-vessel angle. Compared to other indices such as the Laplace transform damping factor, the pulsatility index excels in its simplicity and ease of calculation.[4,5] The first investigators using the pulsatility index in predicting iliac stenoses in humans, showed encouraging results.[6] Later investigations showed that the accuracy of the pulsatility index was limited, especially in patients with combined aortoiliac and femorodistal disease.[7–10]

Two recent lines of investigation using Duplex scanning to detect stenoses in the aortoiliac segment can be distinguished: (1) direct visualisation using colour Duplex scanning and (2) indirect investigations by calculation of stenoses from Doppler wave form analysis distal to the vascular segment or proximally and distally. Legemate *et al.* and Wittens *et al.* both showed that direct Duplex scanning has the advantage of precise localisation of stenoses and a fairly accurate assessment of the haemodynamic significance by Duplex velocity analyses at the observed stenoses.[11–14] The main disadvantage is that the investigation is difficult (especially in obese patients) and time-consuming. Two recent reports show interesting results of indirect investigation of the aortoiliac segment. Sawchuk *et al.* describe a method of calculating the 'mean power frequency index' from the Duplex signal of the aorta and the femoral artery.[15] The transfer function of the velocity wave spectrum is an indicator of the properties of the arterial segment between the measurement points. Comparison with intraarterial pressure measurements shows a good correlation. A disadvantage of the method is the computer required for the calculations. Van Asten *et al.* combine the results of Duplex velocity wave spectra analysis in the common femoral artery before and after induction of reactive hyperaemia.[16] They also claim accurate detection of haemodynamically significant stenoses in the aortoiliac segment compared to intraarterial pressure measurements. The spectrum analysis again requires extra computer equipment.

Although it should theoretically be possible to assess stenoses in the aortoiliac segment by calculation of the RCR before and after exercise-induced hyperaemia, the results presented here suggest that the method has no practical value. We also evaluated the

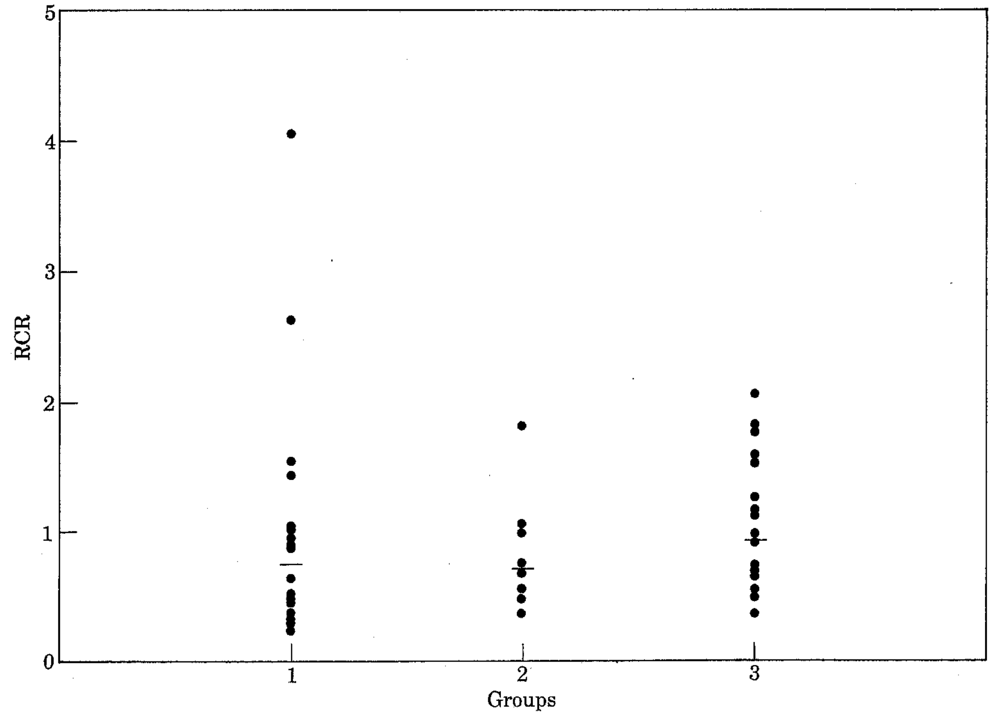


Fig. 2. Results of the Resistance Change Ratio (RCR). On the horizontal axis the three groups with different pressure gradients: group 1 had a pressure gradient of more than 10 mmHg at rest; group 2 had a pressure gradient of more than 10 mmHg after injection of 25 mg papaverine; group 3 had a pressure gradient of 10 mmHg or less. On the vertical axis the RCR values: Horizontal bar = median value. Median values: group 1: 0.74 (range 0.23–4.04); group 2: 0.71 (range 0.36–1.80); group 3: 0.93 (range 0.36–2.06).

results with higher intraarterial pressure gradient values as an indication for haemodynamically significant stenoses in the aortoiliac tract (pressure gradient > 30 mmHg), but again no significant results were obtained. The RCR as calculated is probably dependent on several factors 'masking' the effect of stenoses in the aortoiliac arterial segment. For instance differences in the arterial resistance in the arterioles and capillaries may play a role. This resistance can vary in patients suffering from intermittent claudication, but in patients suffering critical ischaemia the resistance of the small vessels is nearly fixed at the lowest value. We also believe that a treadmill walk is not the best method to induce vasodilatation, especially in the muscles fed by the deep femoral artery. Because the additional flow through the deep femoral artery is one of the pillars of our theory, it might have been better to perform another stress test, i.e. post ischaemic hyperaemia, to induce vasodilatation resulting in a better distinction between the groups. Another problem might be the measurement of the mean blood flow velocity in the common femoral artery with the Duplex scanner. It is known that flow estimation is prone to several sources of error.[17] Because we did not measure flow but mean flow velocity, a change of diameter of the common femoral artery induced by the exercise could also have influenced our results.

In conclusion the RCR could not accurately detect stenoses in the aortoiliac arteries and, although simple and inexpensive, we can therefore conclude that this method is not useful. Other methods have been discussed and seem promising. For now, intraarterial pressure measurement is still the "gold standard".

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