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Blood pressure and effect of exercise in children before and after surgical correction of coarctation of aorta

A EARLEY, M C JOSEPH, E A SHINEBOURNE, M DE SWIET

From the Department of Paediatrics, Cardiothoracic Institute, Brompton Hospital, Fulham Road, London

SUMMARY Systolic blood pressure was measured at rest and during exercise in 43 children who had undergone operation for correction of coarctation of the aorta, five children awaiting surgery for coarctation, and 22 control children. Ages ranged from 2 to 15 years, mean 7·6 years.

The mean blood pressure of children with coarctation in both the pre- and postoperative groups was significantly higher at rest than in the controls. Of 43 postoperative patients, 15 (35%) were hypertensive (systolic blood pressure more than 95th centile), and 12 of these had a gradient between the upper and lower limb. Seven of the 28 normotensive patients also had a gradient postoperatively.

Exercise increased the blood pressure more in children with coarctation than in controls, but there was much individual variability and this difference was not significant. Some children with coarctation developed very high blood pressures on exercise, but this was not related to the presence of a gradient.

The mean interval after operation was significantly shorter in the hypertensive group, independent of the age at operation.

Hypertension with or without a gradient commonly persists despite apparent successful surgical correction, but exercise is of limited value in its assessment in this age group.

It has been shown that there is a significant incidence of premature death in patients surviving operation for coarctation of the aorta, and that cardiovascular disease is the primary cause of these deaths.[1] Hypertension has been established as a major risk factor for cardiovascular disease,[2] and persistence of hypertension after repair of coarctation is likely to be an important factor in these deaths.

The hypertension after resection of coarctation may be in the upper limb only and associated with a gradient between upper and lower limbs, or it may be generalised, that is present in both upper and lower limbs without a gradient. The measurement of blood pressure during exercise may be a more sensitive method of detecting hypertension after operation, also reflecting blood pressure levels during normal activities more accurately than measurements at rest.[3 4] We have therefore measured upper and lower limb pressures in children with previously resected coarctation, some of whom were hypertensive, and have investigated the effect of exercise on the upper limb pressure.

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Subjects and methods

Studies were made of 48 children with coarctation, 29 boys and 19 girls, aged 2 to 15 years. Of these, 43 had had previous surgical repair of their coarctation, and the result had been considered satisfactory. Three patients had had operations in infancy, and now required further operation for recoarctation which had been confirmed at cardiac catheterisation. Two patients who were newly diagnosed were studied before operation. Twenty-two normal children aged 2 to 12 years were used as controls. These were healthy sibs of patients, or relatives of hospital staff.

Seven of the children had other cardiac lesions in addition to coarctation: two had ventricular septal defect (one with the pulmonary artery banded), two had aortic valve disease, one had mitral valve disease, one had complex cyanotic congenital heart disease, and one had had a Mustard operation. Two of the children were taking anti-hypertensive drugs at the time of study. The age at operation ranged from 7 days to 168 months (mean 20 months), and the length of postoperative follow-up ranged from one month to 144 months (mean 73 months).

Measurements were made using the Parks Doppler ultrasound system[5] and a random zero sphygmomanometer.[6] The upper limb blood pressure was measured using a cuff with an inflation bladder 7·6 cm wide and 15·5 cm long for arms with a circumference of 22 cm or less, and with an inflation bladder 12·5 cm wide and 22·5 cm long for arms with a circumference greater than 22 cm. The relation of these cuffs to arm size has previously been evaluated.[7] A 12 cm cuff was used to measure all blood pressures in the leg, as all leg circumferences were greater than 22 cm. Measurements were made in triplicate, and the mean subsequently analysed. The children's weight, maximum arm and leg circumference, and any drug treatment were recorded. The blood pressure was recorded in the right arm sitting, and then in the right leg while the child was sitting with the leg stretched out horizontally. The sitting position was used because we found that younger children were unco-operative when made to lie down for blood pressure measurements. The patients then exercised for three minutes, after which the blood pressure was measured in the right arm with exercise continuing until the measurements were completed. The heart rate was recorded continuously using chest electrodes and an electrocardiographic monitor.

Children aged 7 years and over exercised on a bicycle ergometer with a work load of approximately two watts/kilo body weight, and 60 to 70 pedal revs/minute. The work load was adjusted so that the heart rate remained over 150/minute during exercise. Children younger than 7 exercised on a treadmill, the slope of which was kept at 20 per cent, and the speed increased until the heart rate remained over 150/minute. This heart rate was chosen because it occurs at a work load of approximately half the child's physical working capacity[8] and represents a submaximal exercise level.

A blood pressure gradient was arbitrarily defined as a difference of more than 5 mmHg between the upper and lower limb. We defined hypertensive subjects as those with a systolic blood pressure above the 95th centile for blood pressure as defined by the American task force for blood pressure control in children.[9]

All values have been quoted as means ±SD. The mean values have been compared by Student's t test.

Results

(1) BLOOD PRESSURE AT REST

Fifteen (35%) of the 43 postoperative patients were hypertensive at rest (see Fig. 1); of these, three had systolic hypertension without a gradient, and 12 had a gradient between the upper and lower limb. The gradient varied from 9 to 38 mmHg, mean 20 mmHg. Seven of the normotensive postoperative patients also had blood pressure gradients between the upper and lower limb, and this ranged from 6 to 28 mmHg, mean 14 mmHg. Four of the five patients studied preoperatively (two with recoarctation and two new patients), had upper limb pressures above the 95th centile. One of the five had an unrecordable lower limb blood pressure: the gradient in the other four patients ranged from 26 to 41 mmHg, mean 35 mmHg.

None of the control group was hypertensive (Fig. 1) and values for resting blood pressures in this group corresponded to previously published data for blood pressure in this age group.[9] None of the control group had a gradient between the upper and lower limb.

(2) BLOOD PRESSURE DURING EXERCISE

Fig. 2 and the Table show blood pressure during exercise and at rest in preoperative, postoperative, and control groups. The mean blood pressure was

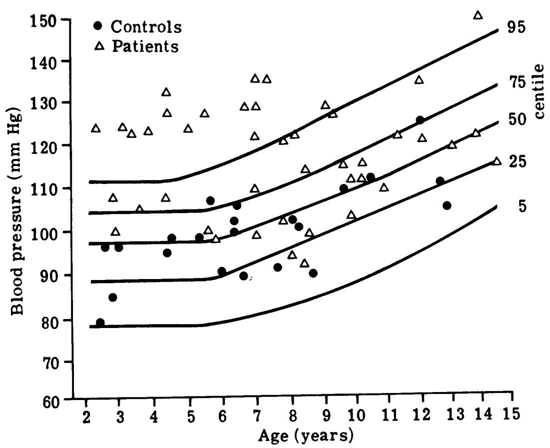

Fig. 1 *Upper limb systolic blood pressures of controls and patients with coarctation postoperatively, measured at rest. Centiles taken from report of task force on blood pressure.*[9]

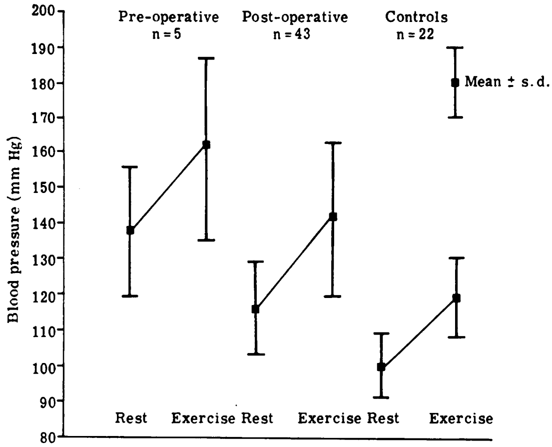

Fig. 2 *Mean increase in blood pressure on exercise in patients with coarctation, before and after operation, and in controls.*

highest, as expected, in the preoperative group, but was also significantly higher than in the controls in the postoperative group, both at rest and during exercise ($p < 0{\cdot}001$).

Upper limb systolic pressure increased on exercise in all the children. The mean increase in blood pressure in children with coarctation was 25 mmHg, but this was not significantly more than in controls, where the mean rise on exercise was 21 mmHg (Table). The mean increases in the hypertensive postoperative group, and in the preoperative group were 24 and 25 mmHg, respectively. The presence of hypertension therefore did not significantly alter the blood pressure response to exercise in these children. Persistence of a gradient between upper and lower limb pressures did not affect the rise in blood pressure on exercise either, as the mean rise in blood pressure in the children with gradients was 21 mmHg.

Two children developed very high blood pressures during exercise—increases of 50 and 80 mmHg. One of these was hypertensive without a gradient, the other was normotensive.

We were unable to relate the presence of hypertension to age at operation, though the interval since operation was significantly shorter in the hypertensive group, independent of age at operation. The mean interval since operation of the hypertensive children was 53 ± 30 months, whereas for the normotensive postoperative group it was 80 ± 37 months ($p < 0{\cdot}01$).

Discussion

We have confirmed other studies which have shown that hypertension remains a considerable problem in children after operation for coarctation[10–12] and that these children have higher blood pressures than controls during exercise as well as at rest.[13] It is likely that this hypertension contributes to the increased incidence of early deaths from cardiovascular disease in these patients. The high incidence of hypertension after operation that we found was not the result of the artificial circumstances of the hospital environment, since the blood pressures of controls, also measured in hospital, were in the normal range.

We found that one-third of our patients were hypertensive. This is a slightly smaller proportion than reported by Maron *et al.*[1] who found that 37 per cent of postoperative patients were hypertensive 11 to 25 years later, though these authors defined hypertension as exceeding the 90th rather than the 95th centile. Nanton and Olley[10] reported that 24 per cent of patients operated on in childhood remained hypertensive at least six months after operation. An earlier study of 87 patients from this department[14] found that the overall incidence of hypertension after operation was 31 per cent. This study also suggested that the incidence of hypertension without a gradient was lower in the group operated on before 1 year than in those operated on later. In this study there were only three such

Table *Upper limb mean resting blood pressure (mmHg ± SD) and effect of exercise*

	No.	*Blood pressure at rest*	*Blood pressure during exercise*	*Blood pressure rise on exercise*
Control	22	100 ±10	122 ±14	21 ±11
Preoperative	5	138 ±18	163 ±25	25 ±14
Postoperative:				
Hypertensive postoperative	15	130 ±7	154 ±17	24 ±12
Postoperative + gradient	19	125 ±9	146 ±14	21 ±10
Total postoperative*	43	117 ±13	143 ±21	25 ±11

* Nine postoperative patients were neither hypertensive nor had a gradient.

hypertensive patients without a gradient, too small a number for valid comparison.

Twelve of our hypertensive patients had a gradient between the upper and lower limb. Opinions differ as to the degree of gradient that is significant. Eshaghpour and Olley[11] suggested that recatheterisation was indicated in any child with a gradient of more than 10 mmHg, and Maron *et al.*[1] also suspected "residual coarctation" in those with this gradient. Using these criteria 15 of our patients (10 of whom were also hypertensive) needed further study. Since in the normal child by the age of 1 year the blood pressure in the leg, measured by the same technique, is already higher than in the arm,[15] it might be argued that those children who have any gradient have some degree of residual coarctation or have recoarctation, though the significance of this in terms of the circulation is not known. In our patients, those with larger gradients also tended to be hypertensive, that is 10 out of 15 patients with gradients greater than 10 mmHg. The gradients reported here are underestimates of the true gradient since we made measurements on the leg with the children sitting. In this position blood pressure in the leg is increased as a result of the hydrostatic effect of a column of blood between the heart and the cuff, and the true leg pressure is therefore lower.

The incidence of hypertension without a gradient in the postoperative patients studied was 7 per cent and was lower than in other series, but more hypertensive patients with a gradient (28%) were found. Nanton and Olley[10] in their series found that 24 per cent of children remained hypertensive after operation, and that this was associated with a gradient in 11 per cent and not associated with one in 15 per cent.

The value of exercise in the assessment of these children is doubtful. Though the mean rise in blood pressure on exercise was greater in those children with coarctation, particularly if they were hypertensive, this difference was not statistically significant, and there was considerable variation. This is shown by the greater standard deviation of exercise blood pressure (14 to 25 mmHg) compared with resting blood pressure (7 to 18 mmHg). Part of this increase in variability is a result of the difficulties of blood pressure measurement during exercise. Freed *et al.*[16] showed a significantly greater rise in blood pressure after "exercise to exhaustion" in 30 postoperative patients, and it is possible that more strenuous exercise levels would have shown a greater blood pressure rise in our patients. The population studied by Freed *et al.*, however, was considerably older than ours, as the mean age was 14 years and the youngest patient was aged 6, whereas the mean age of our study group was 7·6 years and 13 patients were aged 6 or under. The rise in blood pressure on exercise was not related to the presence of a gradient at rest. Freed *et al.*[16] and Connor[17] have shown that the gradient between the upper and lower limb rose after exercise, and Connor has subsequently recommended recatheterisation in some patients on the basis of the postexercise gradient. In our opinion it is not possible to record blood pressure, with any accuracy, when the child had stopped exercising as our experience has shown that it starts to fall the instant exercise stops. This view is held by others.[18 19] Connor states that he measured blood pressure in the leg before the arm after exercise so as to underestimate any increase in gradient that might occur because of decrease in heart rate and cardiac output "in 30 to 45 seconds between measurements". Cumming *et al.*[20] showed that heart rate in children fell from 200 to 120 beats/minute within two minutes of stopping exercise, indicating again that measurements made during recovery from exercise are rapidly changing and inaccurate. We did not study enough children both before and after operation to show whether the rise in blood pressure which occurs preoperatively will predict the effect of surgery on the blood pressure. Our previous experience with exercise tests in a group of children under 6 has shown that attempting more strenuous exercise levels only leads to lack of co-operation. We have been unable to find any published data on exercising very young children and therefore we used Godfrey *et al.'s* criteria[8] of heart rates for submaximal exercise to produce some standardisation of exercise levels. It is, thus, possible that exercising older children who are better able to co-operate and to exercise them to exhaustion may be helpful in the evaluation of the postoperative patient.

It has been shown that exercise blood pressures give a better indication of the blood pressure during normal activities in adults than casual resting measurements,[3 4] and our results did show that two children who were normotensive or mildly hypertensive at rest, developed very high blood pressures during exercise. It is possible that these children should be taking antihypertensive treatment, since cardiovascular complications could be associated with peak rather than resting blood pressure. In fact, only two children were actually receiving treatment, and this may reflect the inaccuracy of pressure measurement or, more likely, a general reluctance to treat hypertension in children especially if it is mild.

Measurement of blood pressure soon after operation was associated with a greater incidence of hypertension. This suggests that the blood pressure may cross centiles and stabilise within normal limits, even if the child remains hypertensive for some months after surgery. Further analysis based on retrospective study of blood pressure recorded in the hospital case notes was not possible, because of inaccurate and varied blood pressure recording techniques. It is possible that the apparent decrease in incidence of hypertension with time occurs because some patients who were lost to follow-up were relatively hypertensive, and some may have died early in the follow-up period because of hypertension. A prospective study is necessary to evaluate these possibilities. Differing surgical techniques are unlikely to account for this observation, as all children studied had a similar operative technique, that is end-to-end anastomosis rather than aortoplasty.

In conclusion, hypertension both with and without a gradient persists in up to one-third of patients after corrective surgery for coarctation, but the usefulness of exercise testing in assessing this in young children is limited by the degree of variation in the individual's blood pressure response to exercise. There may be some value in detecting those children who, though only mildly hypertensive at rest, develop very high blood pressures on exercise.

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Requests for reprints to Dr M de Swiet, Cardiothoracic Institute, Brompton Hospital, Fulham Road, London SW3 6HP.