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Original Article

The influence of different surgical procedures on hypertension after repair of coarctation

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Abstract We measured resting and exercise haemodynamics, as well as 24-hour ambulatory blood pressure, so as to study the influence on development of hypertension in children after repair of coarctation by either construction of a subclavian flap or end-to-end anastamosis. The patients in both groups were studied a mean time of 13 years after surgery. Thus, we divided 43 children who had undergone surgical repair of coarctation, and who were not on antihypertensive therapy, into a group of 22 patients who had undergone subclavian flap repair, with a mean age of 14 plus or minus 2.6 years, and another group of 21 patients undergoing end-to-end anastomosis, with a mean age of 13.5 plus or minus 3.9 years. We examined blood pressure at rest and during exercise, along with the measurement of cardiac output using impedance cardiography, and during 24-hour ambulatory monitoring. We recorded systolic and diastolic blood pressures, pulse pressure, cardiac output and total peripheral vascular resistance at rest and at peak exercise. During ambulatory monitoring, we measured mean pressures over 24 hours, in daytime and nighttime, 24-hour pulse pressure, and 24-hour mean arterial pressure. Student's t test was used to judge significance, accepting this when p was less than 0.05. The group repaired using the subclavian flap showed significantly disadvantageous differences for diastolic blood pressure at rest, systolic blood pressure at peak exercise and for 24-hour systolic and diastolic blood pressure, 24-hour mean arterial pressure, and daytime and nighttime systolic blood pressure during ambulatory monitoring. Our findings suggest that, after repair using the subclavian flap in comparison to end-to-end anastomosis, patients show a higher incidence of late hypertension, both during exercise and ambulatory monitoring. The data indicate different residual aortic stiffnesses, these being lower after end-to-end anastomosis, which may be due to the greater resection of the abnormal aortic tissue when coarctation is repaired using the latter technique.

Keywords: High blood pressure; subclavian flap; end-to-end anastomosis

The introduction of first surgical repair, and now balloon angioplasty, have radically changed the natural history of aortic coarctation, even though long-term follow-up studies still show a limited life expectancy in these patients compared to the general population.[1] The most important complication arising during late follow-up is systolic hypertension, sometimes associated with post-surgical recoarctation. Studies investigating coarctation have underlined the advisability of surgical correction before the age of 6 years to prevent the development of systolic hypertension from mechanisms including the baroceptor reflex, left ventricular hypertrophy, and/or damage to the kidneys and blood vessels.[1–3] Abnormal levels of hypertension are well recognised in the follow-up of such patients after surgical repair, as well as other problems such as recoarctation, aneurysmal formation, and late death.[4–8] To the best of our

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knowledge, however, data concerning haemodynamics and the behaviour of the hypertensive changes has yet to be assembled and compared for groups undergoing different initial surgical procedures, such as construction of a subclavian flap or end-to-end anastomosis. In a pilot study, we demonstrated differences in the blood pressures recorded at follow-up for different groups undergoing correction by one or other of these techniques.[8] In this study, we have extended our pilot investigation, evaluating the profiles for blood pressure in a larger group of patients.

Methods

We enrolled 43 patients, none being on antihypertensive therapy, for participation in our study. The mean period since the initial surgical procedure was 13.2 years, with a range from 6 to 21 years. Selection was based on the absence of associated cardiac abnormalities, albeit that two patients, one in each group had a bifoliate aortic valve without any evidence of regurgitation, a gradient of pressures between the arm and leg at rest less than 15 millimetres of mercury, and only one surgical procedure in the history, with no procedures performed because of recoarctation. Echocardiographically, we required the aortic arch to be apparently normal, with no evidence of residual obstruction or deformity at the site of repair, and with no diastolic flow as seen at Doppler echocardiography. We obtained full informed consent for inclusion in the study, which was approved by our Research Institute Ethics Committee. We enrolled 22 patients who had received a subclavian flap, these patients having a mean age at surgery of 3 months, and 21 who had undergone an end-to-end anastomosis, these having a mean age at surgery of 11.2 months.

Rest

All subjects underwent a physical examination with the measurement of blood pressure at rest using a calibrated Tycos aneroid sphygmomanometer. We measured systolic and diastolic pressures in the right arm with the subject seated, taking the pulse pressure as the difference between the systolic and diastolic values. The cuff size was chosen to comply with the criterions of the Task Force for Blood Pressure Control in Children.[9] For analysis, we used the mean of three separate measurements taken at intervals of 3 to 5 minutes. We also measured pressures at rest in the leg, in the supine position, to determine the gradient between the upper and lower limbs. Pressure in the legs was measured only at rest, because during peak exercise the patients were sitting on the bicycle ergometer in order to obtain the maximal cardiac output.

Exercise

All subjects performed bicycle ergometer exercise testing using the James protocol, which provides for an increment of the workload every three minutes starting with 32, and then 82, 131, 163, and 196 watts.[10] We recorded the time of exercise in minutes and the maximal power in watts, maximal heart rate in beats per minute, and peak systolic and diastolic blood pressures in millimetres of mercury.

Cardiac output

We determined cardiac output at rest and peak exercise using impedance cardiography. This non-invasive technique allows the measurement of cardiac output every beat, but we averaged the values over at least 10 beats to minimize artefacts. The total peripheral vascular resistance was calculated by dividing the mean arterial pressure by the cardiac output multiplied by 80 expressed in dyne per centimetre per second^{-5}. Mean arterial pressure was calculated as systolic pressure plus twice diastolic pressure divided by 3. To evaluate the differences in cardiac output, we indexed the total peripheral vascular resistance for body surface area.

Ambulatory monitoring

All patients performed 24-hour ambulatory monitoring using Spacelab 90207 as developed by Spacelab Inc of Redmond, Washington, United States of America. The equipment was set to obtain readings every 15 minutes from 7:00 in the morning to 11:00 in the evening, and then every 30 minutes for the next 8 hours. Patterns of awakeness or sleeping were established following the daily-activities described in a diary kept by each patient. We calculated the mean of the 24-hour recording, daytime and nighttime systolic and diastolic pressures, 24-hour mean arterial pressure, and 24-hour mean pulse pressure.

Statistical analysis

Student's t test was used to compare the data, taking p values of less than 0.05 to be significant.

Results

At rest, we found significant differences only for diastolic blood pressure (Table 1). At peak exercise, however, those who had undergone an end-to-end anastomosis showed significant advantageous differences for systolic blood pressure and pulse pressure. Those undergoing an end-to-end anastomosis also had better exercise tolerance, with a higher maximal power during the second as opposed to the third stage of the protocol with similar diastolic pressures, and improved maximal heart rate, peak cardiac output, and peak total peripheral vascular resistance (Table 2). During ambulatory monitoring, those undergoing an end-to-end anastomosis showed lower mean values for blood pressure, with significantly advantageous differences for mean 24-hour pressures, daytime and nighttime systolic and diastolic pressures, and 24-hour mean arterial pressure. No difference could be detected for pulse pressure as calculated over the period of 24 hours (Table 3).

In those repaired using the subclavian flap, 14 of the group (64 percent) had a hypertensive response to exercise, and 5 of these (36 percent) had an abnormal ambulatory blood pressure profile,[11] while comparable abnormalities were found in 9 (43 percent), and 5 (55 percent), respectively, of those repaired using an end-to-end anastomosis.

Discussion

Numerous studies have established the increased incidence of hypertension in patients undergoing surgical repair of aortic coarctation, with pressures known to be elevated both during daily-life[1–3] as well as at exercise.[12,13] Leandro et al.[3] reported hypertensive values postoperatively in patients who were normotensive at rest, and who also had a greater left ventricular mass and enhanced contractility of the left ventricle. Johnson et al.[14] evaluated patients using 24-hour ambulatory monitoring either less than or more than ten years following surgical repair. They found exaggerated systolic and diastolic reactivity, with the prevalence of systolic hypertension doubling ten years after surgery.

In our recent study,[15] when comparing such patients to the normal population, we found a greater incidence of hypertension with altered hemodynamics, especially a higher pulse pressure and a decrease of total peripheral vascular resistance with exercise. In particular, we observed that the behaviour of the profiles of hypertension was similar to that observed in older patients with aortic sclerosis, or those with moderate-to-severe aortic regurgitation, these lesions both accentuating abnormalities of the elasticity and compliance of the aortic wall.

Table 1. Anthropometrics and rest data.

	Height	Weight	SBPr	DBPr	ΔA/L	COr	TPVRr	PPr
SF	161 ± 12	56 ± 13	119 ± 12	70 ± 9	3.7 ± 5.9	5.8 ± 1.7	1282 ± 394	49 ± 12
EE	155 ± 15	51 ± 13	112 ± 13	63 ± 9	4.3 ± 6.3	5.8 ± 1.4	1158 ± 278	49 ± 12
	p = n.s.	p = n.s.	p = n.s.	p = 0.02	p = n.s.	p = n.s.	p = n.s.	p = n.s.

Abbreviations: SF: subclavian flap; EE: end-to-end anastomosis; height and weight are expressed, respectively, in centimetres and kilograms; SBPr: systolic blood pressure at rest (millimetres of mercury); DBPr: diastolic blood pressure at rest (millimetres of mercury); ΔA/L: arm–leg gradient at rest (millimetres of mercury); COr: cardiac output at rest (litres/minute); TPVRr: total peripheral vascular resistance at rest (dyne per centimetre per second^{-5}); PPr: pulse pressure at rest (millimetres of mercury)

Table 2. Exercise testing data.

	TE	Watt	SBPp	DBPp	HRm	COp	TPVRp	PPp
SF	8.2 ± 2.3	115 ± 35	175 ± 27	62 ± 10	167 ± 18	12.7 ± 2.4	636 ± 147	115 ± 30
EE	9.3 ± 2.5	135 ± 45	154 ± 24	57 ± 8	168 ± 14	12.5 ± 4.1	630 ± 190	97 ± 28
	p = n.s.	p = n.s.	p = 0.015	p = n.s.	p = n.s.	p = n.s.	p = n.s.	p = 0.06

Abbreviations: SF: subclavian flap; EE: end-to-end anastomosis; TE: time of exercise (minutes); SBPp: systolic blood pressure at peak (millimetres of mercury); DBPp: diastolic blood pressure at peak (millimetres of mercury); HRm: maximal heart rate (beats per minute); COp: cardiac output at peak (litres/minute); TPVRp: total peripheral vascular resistance at peak (dyne per centimetre per second^{-5}); PPp: pulse pressure at peak (millimetres of mercury)

Table 3. Data from ambulatory monitoring over 24 hours expressed as mean plus or minus standard deviation in millimetres of mercury.

	SBP 24-hour	DBP 24-hour	MAP 24-hour	SBP daytime	SBP nighttime	PP 24-hour
SF	122 ± 9	66 ± 8	85 ± 8	127 ± 8	114 ± 10	56 ± 5
EE	114 ± 10	62 ± 5	79 ± 6	117 ± 10	107 ± 11	51 ± 10
	p = 0.009	p = 0.04	p = 0.011	p < 0.001	p = 0.04	p = n.s.

Abbreviations: SF: subclavian flap; EE: end-to-end anastomosis; DBP 24-hour: mean 24-hour diastolic blood pressure; SBP 24-hour: mean 24-hour systolic blood pressure; MAP 24-hour: mean arterial pressure 24-hour; SBP daytime and nighttime: mean systolic blood pressure during daytime and during nighttime; PP 24-hour: mean 24-hour pulse pressure

Pre-existing alterations in the aortic root in patients with aortic coarctation have been described by Sehested et al.,[16] who detected evidence of excessive rigidity and deposition of collagen within the aortic wall in specimens obtained at the time of repair, and from Ong et al.,[17] who found the transverse aorta of patients undergoing successful repair of aortic coarctation to be stiffer than that of normal subjects.

To our knowledge, no data yet exist comparing the profiles of blood pressure during the follow-up of patients undergoing different surgical procedures for the repair of the coarctation. We have now shown that, in our hands, the best results in terms of incidence and degree of hypertension are obtained after an end-to-end anastomosis. The demonstration in these patients of a better pulse pressure, an important parameter when evaluating hypertensive patients,[18,19] both during exercise and daily activities, suggests that the site of repair is more compliant after the end-to-end anastomosis than when the subclavian artery is turned down as a flap. We are well aware that the choice of surgical procedure is usually made in the operating room, depending on the individual anatomic abnormalities. If it is possible to make a choice, however, we would suggest that an end-to-end anastomosis should be the first choice whenever possible, because of the better responses of blood pressure found in late follow-up. We believe that the technique of end-to-end anastomosis allows the maximal possible resection of the abnormal tissues of the aortic wall. In this way, the technique preserves as best as possible the natural aortic elasticity that, when altered, seems to be the cause of hypertension in these patients.

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