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Long-term results of balloon angioplasty for native coarctation of the aorta in childhood in comparison with surgery

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Abstract

OBJECTIVES: Coarctation of the aorta (CoA) can be treated either surgically or with balloon angioplasty (BA). Long-term follow-up for either treatment has been limited. Our objective was to compare long-term results of BA and surgery for treatment of native CoA in childhood.

METHODS: Retrospective cohort study of patients with native CoA treated with BA or surgery between 3 months and 16 years of age. Forty-eight patients filled out questionnaires and approved review of their medical records. Twenty-four patients underwent additional testing, including 24-h ambulatory blood pressure measurement, cardiopulmonary exercise testing and cardiac magnetic resonance imaging. Results were analysed cross-sectionally and longitudinally.

RESULTS: Nineteen and 29 patients received BA and surgery, respectively. Prevalence of hypertension and aneurysms was similar in both groups. Fifty percent of patients were hypertensive. Two-thirds of patients demonstrating hypertension were not receiving antihypertensive medication. Aneurysm formation occurred in 1 BA (5%) and 1 surgery (3%) patient. The BA group had a significantly higher risk of recoarctation (47% vs 24%) and reintervention (hazard ratio 2.95, 95% confidence interval 1.04–8.32). Exercise capacity and global left ventricular function were preserved in both groups and not significantly different after correction for age. Quality of life was good to excellent in the majority of the patients.

CONCLUSIONS: After CoA repair in childhood, most patients perform well in daily life. However, on the long term, more than half of the patients develop hypertension and many develop re-CoA, especially in those who underwent BA. Therefore, we do not recommend BA for the treatment of native CoA in children.

Keywords: Congenital heart disease • Coarctation of the aorta • Paediatrics • Balloon angioplasty • Surgery

INTRODUCTION

Aortic coarctation (CoA) is a common congenital cardiac lesion in children, which accounts for 8–10% of all congenital heart defects. Untreated CoA causes morbidity and early demise by way of hypertension, congestive cardiac failure, myocardial infarction, stroke, infective endocarditis and aortic rupture [1]. After initial repair, several complications may develop, including hypertension, restenosis and aneurysmal dilatation of the repair site [2, 3]. However, the exact prevalence and potential adverse impact on the outcome of these complications are largely unknown.

Open surgery was the only treatment for CoA until balloon angioplasty (BA) was introduced as an alternative therapy in the 1980s [4]. Since then, aortic angioplasty, thought to be safer and less invasive, has been adopted for CoA therapy. In 2005, Cowley *et al.* [3] published the results of a long-term, randomized trial comparing BA and surgery for native CoA in childhood. They concluded that BA is associated with a higher incidence of aneurysm formation than surgery. Other studies found a higher incidence of re-CoA in children treated with BA compared with surgery [5, 6]. Because of the suspected higher complication rate, BA as primary therapy for CoA has become controversial.

However, in a study performed in our centre, with a follow-up of 1–10 years, no differences in the development of re-CoA and aneurysm formation were observed [7]. Whether long-term complication rates (>10 years) are similar as well remains unclear. If the incidence of re-CoA and aneurysm formation in patients treated with BA is indeed no higher than in surgical patients, reintroduction of this technique should be considered.

This study therefore aimed to investigate the long-term outcome after repair of CoA in childhood and compare the complication rate between patients treated with BA and surgery.

METHODS

Patients

To investigate the long-term outcome of treatment of CoA in childhood, we performed a retrospective cohort study. Only patients with coarctation of the localized membranous form were included. Patients with isthmus hypoplasia, defined as an isthmus diameter less than 40% of the diameter of the ascending aorta, or arch hypoplasia, defined as a proximal or distal transverse arch diameter less than 60% or 50% of the diameter of the ascending aorta, respectively, were excluded. Other inclusion criteria included first CoA procedure between 3 months and 16 years of age and a follow-up of at least 10 years. Children who had their first CoA procedure before the age of 3 months were excluded from this study, because all ($n = 88$) of these patients had severe CoA and had a duct-dependent systemic circulation and moderate-to-severe left ventricular dysfunction. All of these patients underwent surgery. Consequently, inclusion of cases below 3 months of age would result in different patient characteristics between surgery and BA patients and would result in confounding by indication. We excluded patients with severe associated congenital heart defects (e.g. hypoplastic left heart syndrome and transposition of the great arteries).

BA was performed between 1990 and 2001. Before 1990, only surgery was performed. After 2001, surgery or BA with stent placement (in the case of re-CoA) was performed. Consequently, treatment (surgery or BA) was determined by the date of intervention and not by the severity of the stenosis or other patient characteristics. Because the 2 groups of patients were not contemporary, the surgery patients were older and had a longer follow-up than the BA patients at the time of this study. Patients who underwent BA with stent placement for native CoA were excluded from this study.

Recruitment

All patients who underwent primary repair of CoA in our hospital between 3 months and 16 years of age between 1969 and 2004 were asked to participate in our study. Patients were asked to fill out a questionnaire and undergo several medical tests, including 24-h ambulatory blood pressure measurement, cardiopulmonary exercise testing (CPET), cardiac magnetic resonance (CMR) imaging and echocardiography. Patients who declined to undergo medical testing were asked to only fill out the questionnaires. This study was approved by Medical Ethics Committee of the University Medical Center Utrecht (NL39345.041.12).

Primary interventions

BA was carried out under complete anaesthesia. There were no important differences in technique or equipment over the study period [7]. Aortic arch angiography was performed, and the aortic diameter at the level of the diaphragm was measured. The balloon catheter was advanced up to the aortic arch, deflated and then retracted until the balloon crossed the coarctation. Inflation with diluted contrast was performed until the waist in the balloon disappeared. This procedure was performed 3 times, to optimize the final result. A catheter was passed over the guide wire to measure aortic pressures and perform an angiogram. The procedure was repeated using a larger balloon diameter when the result was unsatisfactory. The size of the balloon did not exceed the aortic diameter, measured at the level of the diaphragm, initially, and (if necessary) in a secondary stage not by more than 2 mm.

Three different surgical procedures were performed. The majority underwent coarctectomy with end-to-end anastomosis or patch angioplasty. One patient received an interposition graft.

Testing

CMR studies were performed on a 1.5-T scanner (Ingenia R4.1.2; Philips Healthcare, Best, Netherlands). Stenosis or dilatation at the repair site was determined by comparing the aortic diameter at the repair site relative to the aortic diameter at the level of the diaphragm, the 'repair site-to-diaphragm ratio' (RDR), expressed as a percentage [8, 9]. Any stenosis was defined as RDR $\leq$70% or less and significant (moderate–severe) stenosis as RDR $\leq$50%. Dilatation was defined as RDR >150%. The dimensions of discrete dilatations were measured in 2 orthogonal orientations and the largest diameter was used. Volumetric analysis including left ventricular ejection fraction (LVEF) and mass (indexed to body surface area) was performed offline using QMass Enterprise Solution (Medis Medical Imaging Systems, Leiden, Netherlands).

Patients underwent CPET according to the Godfrey protocol [10]. CPET was performed on an electronically braked upright cycle ergometer (Lode Corival, Lode BV, Groningen, Netherlands), which is calibrated annually. Throughout the test, patients breathed through a face mask (Hans Rudolph Inc., Shawnee, KS, USA) connected to a calibrated metabolic cart (ZAN 600, Accuramed BVBA, Lummen, Belgium). Volume measurements and breath-by-breath respiratory gas analyses were performed with a flow meter and gas analyser for oxygen and carbon dioxide. Oxygen output (VO_2), carbon dioxide output (VCO_2) and the respiratory exchange ratio were automatically calculated using conventional equations. Heart rate (HR) and oxygen saturation were measured continuously with a 12-lead electrocardiogram (Spacelabs Cardioperfect, itMedical, Veenendaal, Netherlands) and pulse oximeter (Masimo Rad8, Masimo BV, Tilburg, Netherlands) fitted on the forehead. The pulse oximeter was verified with the electrocardiographic heart rate. Results were only included for analysis when exercise was performed to exhaustion, with maximal effort defined [11]. Subjective signs of maximal effort were unsteady biking, sweating, facial flushing and clear unwillingness to continue, despite strong verbal encouragement and objective signs of maximal effort were a peak respiratory exchange ratio >1.0 or 1.1 for children and adults, respectively. The test was terminated when the participant could no longer maintain the minimum required pedaling rate of 50 revolutions $\cdot$ min^{-1}.

Peak aerobic capacity was calculated as the peak oxygen uptake averaged over the last 30 s of the test and expressed as VO_2peak corrected for body weight (VO_2peak/kg; ml $\cdot$ kg^{-1} $\cdot$ min^{-1}).

Maximal exercise values were expressed as a percentage of predicted (VO_2peak/kg %predicted) using reference values of healthy Dutch adolescents who were tested using the same protocol and equipment, except for peak blood pressure, for which German reference values were used [12].

Hypertension was defined as a mean 24-h ambulatory blood pressure >135/80 mmHg for adults [13] and an SDS score >2 for children [14]. Ambulatory blood pressure measurement was performed according to the protocol of the European Society of Hypertension [15]. Patients filled out specifically designed questionnaire on their medical history, current health and cardiovascular risk factors as well as a Short Form 36 questionnaire to assess the quality of life.

Statistics

Differences in outcome between patients treated with BA and surgery were analysed using Student's *t*-test for normally distributed continuous outcomes, Mann–Whitney *U*-test for non-normally distributed continuous variables and χ^2 test for dichotomous variables.

Kaplan–Meier curves were constructed to determine intervention-free survival in both groups. Differences in survival were analysed using a Cox proportional hazards model.

Test results with a *P*-value <0.05 were considered significant. All analyses were performed using IBM SPSS Statistics, version 12.

RESULTS

A total of 72 patients were asked to participate. Forty-eight of them filled out questionnaires about their past and current medical situation and gave consent to review their medical records for this study. Twenty-four patients agreed to undergo additional testing, including magnetic resonance imaging (MRI) and exercise testing. There were no differences in baseline characteristics and outcome parameters between the patients that filled out the questionnaires and the participants of the additional testing.

Of the 48 patients, 19 had BA as primary treatment for CoA and 29 underwent surgery (Table 1). Of these 29 patients, 20 underwent coarctectomy with end-to-end anastomosis, 15 patch angioplasty, 1 had an interposition graft and in 3 patients the exact surgical procedure could not be retrieved.

Age at the first procedure was similar in both groups (~5 years). Since BA was not performed before 1990, the year of birth in the BA group was higher, and the mean duration of follow-up was shorter compared with the surgery group.

There was no statistically significant difference in the prevalence of bicuspid aortic valve or other cardiac anomalies between the 2 groups (Table 2).

More than half of the patients reported to have experienced hypertension at some point after repair (Table 3). This was not different between the 2 groups. There was a higher prevalence of re-CoA in the BA group compared with the surgery group (47% and 24%, respectively), but this difference was not statistically significant ($P = 0.09$). All patients with re-CoA underwent reintervention. Two patients in the BA group and 1 patient in the surgery group underwent a third procedure. Aneurysm formation was rare in our patients: only 2 patients (1 BA and 1 surgery) developed an aneurysm according to their medical records.

Reintervention-free survival is displayed in Fig. 1. BA patients had a significantly higher risk of reintervention compared with surgery (hazard ratio 2.95, 95% confidence interval 1.04–8.32). Twenty years after the first procedure, 54% of the BA group and 22% of the surgery group had undergone a second intervention. The average time between the first and the second intervention was 14 years (range: 2–40 years). The types of interventions and reinterventions are displayed in Fig. 2.

The quality of life of patients with CoA did not seem to be affected. Quality of life was very good or excellent in 50% and 47% and good in 50% and 42%, for BA and surgery respectively. Quality of life was moderate in 10% of the surgery patients, but all of these patients also suffered from non-cardiac diseases.

Additional testing

The mean age (standard deviation) of the participants at the day of study was significantly lower in the BA group compared with the surgery group [22.3 (6.7) and 35.9 (8.8) years, respectively].

Half of the patients who underwent additional testing had hypertension on 24-h ambulatory blood pressure testing (Table 4). This did not differ between groups. Only 4 (33%) of the hypertensive patients, diagnosed with ambulatory blood pressure measurement, were using antihypertensive medication.

One patient in the surgery group had a mild stenosis at the CoA repair site and 1 patient in the BA group had a significant restenosis and was referred for BA with stent placement. Only 1 patient (surgery group) had a dilatation and aneurysm at the repair site. Two patients in the surgery group had a decreased LVEF, and the average LVEF was significantly lower in the surgery group compared with the BA group.

At cardiopulmonary exercise testing, BA patients reached a significantly higher peak heart rate and a higher peak work rate (Table 4). Furthermore, they had a better aerobic capacity. However, when corrected for age, height and gender, no significant differences were found between the 2 groups. Mean systolic blood pressure at peak exercise as percentage of predicted (standard deviation) was 102 (14)%. There was no significant difference in peak systolic blood pressure between BA and surgery ($P = 0.64$).

Five (4 BA and 1 surgery) of the 24 participants indicated that they were not under medical follow-up, because they thought their disease had been cured and/or had no medical complaints. Two of them (40%) had hypertension.

DISCUSSION

This study on the long-term outcome of patients treated for CoA between the age of 3 months and 16 years demonstrated that the prevalence of hypertension and recoarctation is high. In contrast to previous studies, the prevalence of aneurysm formation is low, even in the BA group. However, patients treated with BA have a 3 times higher hazard for reintervention compared with surgery. CoA intervention does not seem to affect global cardiac function and exercise capacity many years after the intervention. Although LVEF was significantly lower in the surgery group compared with BA, mean LVEF was within normal range (>55%) in both groups.

As a less invasive treatment, BA was expected to replace surgery in treating CoA. However, the number of randomized trials comparing BA and surgery is still limited. In the past years,

Table 1: Characteristics of the study population

	Balloon angioplasty (*n* = 19)	Surgery (*n* = 29)	Total (*n* = 48)	*P*-value
Gender (male, %)	18 (95)	13 (45)	31 (65)	<0.001
Year of birth	1992 (7)	1979 (10)	1984 (11)	<0.001
Age at first procedure (years, SD)	4.9 (5.2)	5.4 (4.7)	5.2 (4.9)	0.69
Age at study (years, SD)	22.0 (7.3)	34.3 (10.2)	29.4 (10.9)	<0.001
Years of follow-up (SD)	17.1 (2.9)	28.8 (9.7)	24.2 (9.6)	<0.001
Full study participation (%)	10 (53)	14 (48)	24 (50)	0.77

Table 2: Presence of associated anomalies in study population

	Balloon angioplasty (*n* = 19)	Surgery (*n* = 29)	Total (*n* = 48)	*P*-value
Bicuspid aortic valve (%)	10 (53)	13 (45)	31 (65)	0.60
Other cardiac anomaly (%)	4 (21)	6 (21)	10 (21)	0.98
Aortic stenosis (valvular)	1	0	1	
Aortic stenosis (subvalvular)	0	1	1	
Atrial septal defect	1	1	2	
Ventricular septal defect	1	4	5	
Mitral valve dysplasia	1	0	1	
Turner syndrome	0	2	2	0.51[a]

[a]Fisher's exact test.

Table 3: The presence of CoA-related complications (obtained from questionnaires and medical records)

	Balloon angioplasty (*n* = 19)	Surgery (*n* = 29)	Total (*n* = 48)	*P*-value
Hypertension, ever (%)	9 (47)	15 (55)	25 (52)	0.60
Hypertension, now (%)	4 (21)	9 (31)	13 (27)	0.45
Re-CoA (%)	9 (47)	7 (24)	15 (31)	0.09
Aneurysm (%)	1 (5)	1 (3)	2 (4)	0.76
Second CoA procedure (%)	9 (47)	7 (24)	16 (33)	0.09
Third CoA procedure (%)	2 (11)	1 (3)	3 (6)	0.56[a]

CoA: coarctation of the aorta.
[a]Fisher's exact test.

several observational reports and case-matched studies have been published, but the number of patients enrolled in each trial is small, and the statistical power of most trials is too low to document significant differences in clinical outcomes between surgery and BA. Therefore, the issue of whether BA could take the place of surgery is still a matter of debate.

In an earlier study from our centre on the short-term results (mean follow-up of 7 years) of the treatment of CoA in children, there was no mortality and no differences in pressure gradient decrease and morbidity were found between BA and surgery [7]. A meta-analysis on the outcomes BA versus surgery for native CoA was recently published [16]. The quality of the evidence ranged from very low to moderate for the following reasons: (i) lack of allocation concealment and blinding, (ii) small number of patients and (iii) publication bias. The investigators included 9 studies. After >1 year of follow-up, 23 of the 147 BA patients (15.6%) and 3 of the 228 surgery patients (1.3%) had developed an aneurysm ($P = 0.0001$). However, there was a significant variation in aneurysm formation between studies, varying between 0% and 44% in the BA group and 0% and 13% in the surgery group [15]. One explanation for the enormous variation in aneurysm formation in the BA group is differences in BA technique between centres, including type of balloon, balloon size, balloon pressure and number of inflations. In our population, only 5% of BA patients developed an aneurysm. Unfortunately, we were not able to compare BA technique in our centre with the technique of the centre with the highest prevalence of aneurysms, because the technique was not described in that study [17]. Variation in prevalence of aneurysms could also be explained by differences in screening for aneurysm formation. In a previous study from

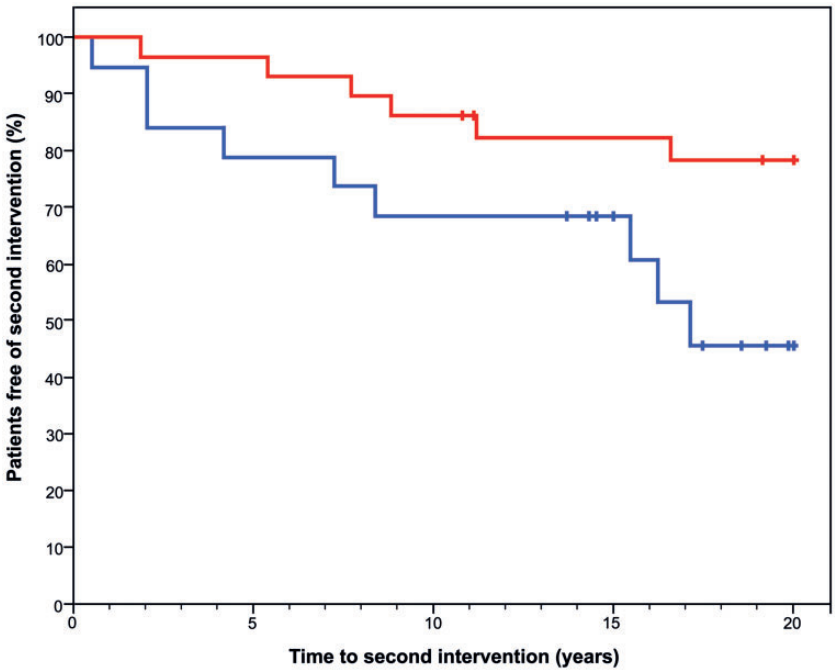

Figure 1: Intervention-free survival after the first procedure for coarctation of the aorta in children between 3 months and 16 years of age, managed with balloon angioplasty (blue) and surgery (red). Hazard ratio 2.95 and 95% confidence interval 1.04–8.32.

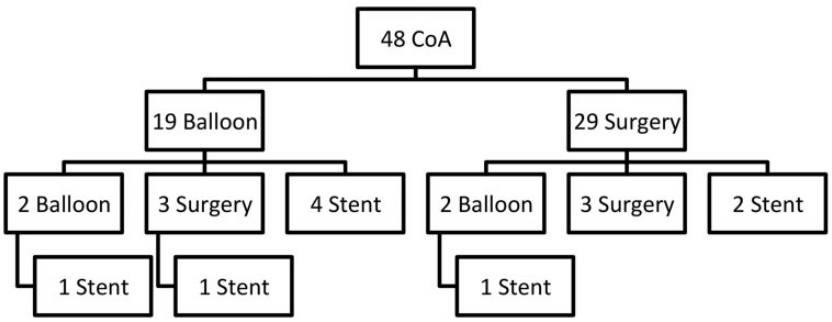

Figure 2: Interventions and reinterventions in 48 patients with CoA, treated with balloon angioplasty or surgery between 3 months and 16 years of age. CoA: coarctation of the aorta.

our centre, patients were screened with echocardiography, which is a less sensitive method for detection of aneurysms than computed tomography or MRI [18]. Most other studies used computed tomography, MRI or angiography to screen for aneurysms. However, patients in this current study, who underwent CMR imaging for the detection of aneurysms, also had a low prevalence of aneurysms: 0 patients in the BA group and 1 in the surgery group. Furthermore, the age at primary repair may play a role. In some studies, the results were biased, because surgery was performed in younger children and BA in older children. In our study, we excluded patients <3 months of age, and there was no significant difference in age at the first procedure between the 2 groups. Finally, confounding by indication may play a role: in several studies, patients with less severe CoA and, consequently, a lower risk for aneurysm formation received BA, whereas more severe cases underwent surgery. The previous study from our centre has demonstrated that there are no differences in baseline aortic gradient between the BA and surgery in our patients [7].

In a meta-analysis of 4 studies on the development of re-CoA >5 years after BA and surgery, 31 of 103 (30%) patients and 48 of 176 (27%) patients, respectively, had developed re-CoA ($P = 0.11$). In our study, a significant difference in re-CoA was also absent. However, this lack of difference could be due to longer follow-up in the surgery group and, consequently, a longer time span to develop re-CoA in these patients. Longitudinal analysis of reinterventions for re-CoA showed a 3 times higher hazard for reintervention in patients who underwent BA compared with patients who underwent surgery.

The arguments for the observed differences in prevalence of aneurysms apply for the difference in prevalence of re-CoA as well. Less aggressive BA in our patients may have resulted in a higher risk to develop re-CoA and a lower risk to develop an aneurysm compared with other studies. The prevalence of re-CoA in our patients, both in the BA and in the surgery group, is relatively high compared to other studies [3, 19]. This difference could be explained by a significantly longer follow-up in our patients (mean follow-up of 24 years).

Table 4: Test results of 24-h ambulatory blood pressure measurement, cardiac MRI and cardiopulmonary exercise testing

	Balloon angioplasty ($n = 19$)	Surgery ($n = 29$)	Total ($n = 48$)	P-value
Hypertension (%)	5 (50)	7 (50)	12 (50)	1.0[a]
Aortic arch abnormality (MRI)				
Any stenosis (%)[a]	1 (10)	1 (7)	2 (8)	1.0[b]
Significant stenosis (%)[a]	1 (10)	0 (0)	1 (4)	0.42[b]
Dilatation (%)[a]	0 (0)	1 (7)	1 (4)	1.0[b]
Aneurysm (%)	0 (0)	1 (7)	1 (4)	1.0[b]
Function of LV (MRI)				
Ejection fraction (%)	60.9 (3.8)	56.9 (4.8)	58.7 (4.7)	0.05
Ejection fraction <55% (%)	0 (0)	2 (17)	2 (9)	0.48[b]
Maximal exercise				
HRpeak (beats/min)	190 (14)	171 (19)	179 (19)	0.02
RERpeak	1.13 (0.11)	1.12 (0.07)	1.13 (0.09)	0.85
Wpeak/kg (W/kg)	3.88 (0.64)	2.97 (0.93)	3.36 (0.92)	0.02
Wpeak (% of predicted)	107 (24)	114 (22)	111 (22)	0.53
VO_2peak (ml/min/kg)	46.3 (8.8)	36.3 (12.5)	40.7 (11.9)	0.05
VO_2peak (% of predicted)	107 (19)	102 (23)	105 (21)	0.58
Peak O_2 pulse (% of predicted)	107 (21)	106 (24)	106 (22)	0.98
Peak systolic BP (mmHg)	214 (17)	201 (27)	207 (24)	0.21
Peak systolic BP (% of predicted)	101 (10)	103 (17)	102 (14)	0.64
VE/VCO_2 slope	22.8 (4.6)	24.3 (4.6)	23.6 (4.6)	0.45

HRpeak: peak heart rate; RERpeak: peak respiratory exchange rate; VO_2peak: peak oxygen uptake; Wpeak: peak workload; BP: blood pressure; VE/VCO_2 slope: minute ventilation carbon dioxide production relationship; RDR: repair site/diaphragm ratio.
[a]Any stenosis: RDR ≤70%; significant (moderate–severe) stenosis: RDR ≤50% and dilatation: RDR >150%.
[b]Fisher's exact test.

Hypertension is a frequent complication in patients with CoA. More than half of our patients experienced hypertension after CoA repair. This hypertension could be due to re-CoA, but several patients without re-CoA were also hypertensive. Even in the infant CoA population, hypertensive changes have been described in the vasculature of the aortic arch, which may explain the development of hypertension in some children despite early and successful CoA repair [20]. There was no difference in hypertension between the BA and surgery group, but these results may be confounded by a higher age of the surgery group. Unfortunately, the number of patients included did not allow for correction for age using multivariate analysis.

Only one-third of the patients who showed hypertension on 24-h ambulatory blood pressure measurement were using antihypertensive medication. Most of these patients were unaware of their hypertension. Furthermore, some patients were not under medical follow-up and had not seen a doctor for more than 5 years. Forty percent of these patients had hypertension. This stresses the importance of careful lifelong follow-up of patients after CoA repair, with regular 24-h ambulatory blood pressure measurements.

On average, patients showed good global systolic function of the left ventricle. LVEF was lower in the surgery group, which was likely due to the higher age of the surgery group, with mean LVEF within normal range.

The participants in our study performed well on CPET. The mean aerobic capacity was 105% of predicted and the peak work load was 111% of predicted. After correction for age and gender, there was no significant difference in results between the 2 procedures. Mean peak systolic blood pressure was only 102% of predicted. This is probably due to the reference values used, which correct for peak work load [12]. Because our participants had a peak work load that was above average (111%), the peak blood pressure measurements as a percentage of predicted are likely underestimated. Peak oxygen uptake was similar in both groups. Patients in our cohort showed a relatively high oxygen uptake compared with earlier reported data on cardiopulmonary exercise testing in CoA patients [21]. No significant difference was seen in the VE/VCO_2 slope between BA and surgery ($P = 0.46$). A higher VE/VCO_2 slope is a risk factor for development of hypertension. However, the mean VE/VCO_2 slope remained within normal range (<27) in both groups [21]. Coarctation patients have the highest exercise capacity among Grown Ups with Congenital Heart defects (GUCH) patients [22]. However, our values are significantly higher than previously reported in CoA patients [22].

Limitations

The present study was limited to a retrospective analysis with unbalanced patient numbers in the 2 groups. The relatively small sample size in the BA group might have reduced the power to detect differences between the 2 groups. Additionally, the higher age in the surgery group at the time of this study may have resulted in an overestimation of complications compared with the BA group. Thus, the potential bias might have relatively optimized the results for the BA group.

CONCLUSION

This study on the long-term follow-up after CoA repair in childhood demonstrates that most patients are doing well in daily life,

with a good exercise capacity and a good quality of life. However, more than half of the patients develop hypertension and a large number of patients develop re-CoA, especially those who underwent BA (3 times higher hazard).

On the basis of these results, we do not recommend BA as primary therapy for native CoA. Angioplasty with intravascular stent placement has become a possible alternative to BA and surgery. Stent placement has the advantage of being less invasive than surgery and having lower complication rates than BA [17]. Furthermore, it is recommended as first-choice treatment of CoA in adults with CoA [23]. With new expandable stents, this treatment may also be a good option for children. However, because of somatic growth of children, there is a need for further redilatation after stent implantation [24]. Furthermore, stent placement cannot be judged superior, as long as long-term beneficial results of stent placement compared with surgery in children are not available. The ESC Guideline for the management of grown-up congenital heart disease recommends 'regular follow-up at least every second year including evaluation in specialized GUCH centers. Imaging of the aorta (preferably with CMR) is required to document the post-repair or post-interventional anatomy and complications' [23]. The results of this study underscore the importance of this recommendation.

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