Advances in the management and surveillance of patients with aortic coarctation
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Chapter 4

Comparison of polytetrafluoroethylene patch aortoplasty and end-to-end anastomosis for coarctation of the aorta

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Abstract

Objectives:
Although aneurysm formation and recoarctation following Dacron patch aortoplasty have been reported on extensively, less is known about these outcomes following polytetrafluoroethylene patch repair, which was compared to resection and end-to-end anastomosis in this study.

Methods:
262 children had surgical repair of coarctation of the aorta by either resection and end-to-end anastomosis (n=137, mean age 1.85 ± 3.1 years) or polytetrafluoroethylene patch aortoplasty (n=118, mean age 1.09 ± 1.9 years) during a 28-year period. Coarctation was isolated in 109 (41.6%), associated with VSD in 77 (29.4%) and with complex intracardiac anomalies in 76 patients (29.0%). Follow-up ranged from 2 days to 29.3 years (median 11.9 years). 7 patients were lost to follow-up. Kaplan-Meier survival curves were estimated and multivariable Cox regression analysis was performed for several outcome variables.

Results:
Mortality was 8.2% and was associated with intracardiac pathology in all cases. Recoarctation occurred in 53 patients, 23 following resection and anastomosis and 30 following patch repair, not differing statistically (log rank, p=0.4). Aneurysm formation occurred in 8 patients following patch repair, that included ridge resection in 7/8 patients. Late hypertension occurred in less patients (n=3) following resection and anastomosis than following patch repair (n=8) (log rank test, p<0.03). Arch hypoplasia (p<0.01) and age < 1 month (p<0.001) were found to be independent risk factors for recoarctation.

Conclusions:
Polytetrafluoroethylene patch repair including coarctation ridge resection was found to be a risk factor for aneurysm formation and late hypertension. Arch hypoplasia and young age must be considered to predispose to recoarctation.
Comparison of different types of coarctation repair

Introduction

Aneurysm formation following Dacron patch aortoplasty for coarctation of the aorta has been reported on extensively, in as much as 51% of patients.\(^1\) However, aneurysm incidence following repair with polytetrafluoroethylene (PTFE) appears to be comparable to other techniques.\(^2\) Among a variety of surgical techniques, we have continued to perform patch aortoplasty with PTFE as patch material in the recent past. The objectives of this retrospective review were threefold. Our first intent was to evaluate the immediate results and long-term follow-up regarding mortality, recoarctation, aneurysm formation and late hypertension following coarctation repair in all age groups with resection and end-to-end anastomosis (RETE) and patch angioplasty (PA). The second goal was to compare those results for both surgical techniques, to identify the ideal form of surgical management or specify indications for these techniques. The third and final objective was to identify risk factors for various outcomes, on which our surgical management can be based.

Patients and methods

Patients

Between 1973 and 2000 262 children had surgical repair of coarctation of the aorta by either RETE or PTFE patch aortoplasty. Of the total, 163 were males and 99 females. Diagnoses included isolated coarctation of the aorta in 109/262 (42%) (group 1), coarctation of the aorta and VSD in 77/262 (29%) (group 2) and coarctation of the aorta with complex intracardiac anomaly in 76/262 (29%) patients (group 3). Associated cardiovascular anomalies and non-cardiac anomaly syndromes are summarized in Table 1.

The mean age at the time of surgery was 1.85 ± 3.1 years for RETE (n=137) and 1.09 ± 1.9 years for PA (n=117). Percentages of female patients were 39% (55/141) for RETE and 64% (44/121) for PA. Percentages of group 2 and 3 pathology were 31 (44/141) and 25 (35/141) for RETE and 27 (33/121) and 34 (41/121) for PA respectively. Associated isthmus hypoplasia was defined as isthmus diameter less than 40% of diameter of ascending aorta.\(^3\) Arch hypoplasia was defined as proximal or distal transverse arch diameter less than 60% or 50% respectively of the diameter of the ascending aorta.\(^3\) Isthmus and/or arch hypoplasia was present in 25/109 (23%) patients in group 1, 36/77 (47%) in group 2 and 23/76 (30%) in group 3. Age at presentation ranged from birth to 15.4 years (median 41 days) in group 1, from birth to 12.0 years (median 21 days) in group 2 and from birth to 11.0 years (median 22 days) in group 3. Method of diagnosis included blood pressure measurement and echocardiography in all patients. Additionally, catheterization was performed in patients in group 3 and in patients in whom echocardiography was not conclusive.
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Surgical management

During the study period, two surgeons performed the vast majority of surgical procedures. Repair-operative approach was left thoracotomy in group 1 and in patients with a staged repair in groups 2 and 3. Median sternotomy was the approach for complete repair in groups 2 and 3. A one-stage repair was undertaken in 16/153

Table 1. Associated cardiovascular anomalies and non-cardiac anomaly syndromes

<table>
<thead>
<tr>
<th>Associated cardiovascular anomalies</th>
<th>No. (rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (Group 1)</td>
<td>111 (41%)</td>
</tr>
<tr>
<td>VSD (Group 2)</td>
<td>80 (30%)</td>
</tr>
<tr>
<td>Perimembranous</td>
<td>45 (56%)</td>
</tr>
<tr>
<td>Muscular</td>
<td>18 (23%)</td>
</tr>
<tr>
<td>Outlet</td>
<td>9 (11%)</td>
</tr>
<tr>
<td>Multiple</td>
<td>5 (6%)</td>
</tr>
<tr>
<td>Inlet</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Apical</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Doubly committed</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Complex anomalies (Group 3)</td>
<td>78 (29%)</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>25</td>
</tr>
<tr>
<td>+ VSD</td>
<td>3</td>
</tr>
<tr>
<td>Mitral valve anomaly</td>
<td>18</td>
</tr>
<tr>
<td>Transposition of great arteries</td>
<td>6</td>
</tr>
<tr>
<td>+ VSD</td>
<td>9</td>
</tr>
<tr>
<td>AVSD</td>
<td>5</td>
</tr>
<tr>
<td>Double outlet right ventricle</td>
<td>1</td>
</tr>
<tr>
<td>+ VSD</td>
<td>4</td>
</tr>
<tr>
<td>Single ventricle</td>
<td>2</td>
</tr>
<tr>
<td>+ VSD</td>
<td>2</td>
</tr>
<tr>
<td>Unspecified</td>
<td>3</td>
</tr>
<tr>
<td>Non-cardiac anomaly syndromes</td>
<td></td>
</tr>
<tr>
<td>Multiple congenital malformations, unspecified</td>
<td>4</td>
</tr>
<tr>
<td>Down’s syndrome</td>
<td>4</td>
</tr>
<tr>
<td>DiGeorge’s syndrome</td>
<td>3</td>
</tr>
<tr>
<td>Schizis</td>
<td>2</td>
</tr>
<tr>
<td>VATERR-association</td>
<td>2</td>
</tr>
<tr>
<td>Turner’s syndrome</td>
<td>2</td>
</tr>
<tr>
<td>Microphthalmia, micrognatia</td>
<td>1</td>
</tr>
<tr>
<td>Brown’s syndrome</td>
<td>1</td>
</tr>
<tr>
<td>Williams-Beuren’s syndrome</td>
<td>1</td>
</tr>
<tr>
<td>Multiple skeletal malformations, unspecified</td>
<td>1</td>
</tr>
<tr>
<td>CHARGE-association</td>
<td>1</td>
</tr>
</tbody>
</table>

VSD = Ventricular septal defect, AVSD = atrioventricular septal defect, VATERR = vertebral defects, imperforate anus, tracheoesophageal fistula, and radial and renal dysplasia; CHARGE = coloboma, heart disease, atresia choanae, retarded growth and development and/or central nervous system anomalies, genital hypoplasia, and ear anomalies and/or deafness.
(10%) patients in groups 2 and 3. The initial procedure in all other patients consisted of aortic arch repair; close follow-up with echocardiographic monitoring indicated the need and timing of a subsequent procedure. Repair consisted of resection and end-to-end anastomosis in 137/262 (52%) patients and PTFE patch aortoplasty in 125/262 (48%) patients. A combination of both techniques in one procedure was performed in 4/262 (1.5%) patients. This combined technique was performed in patients in whom a primarily performed resection and end-to-end anastomosis did not relieve the aortic gradient satisfactory. Patch aortoplasty was performed subsequently within one session. These four procedures were considered primary failures of resection and end-to-end anastomosis. The technique of repair that was used, varied according the surgeon’s preferences predominantly. The coarctation ridge was excised in the performance of patch aortoplasty until 1991. All surgical procedures until mid 1980’s were performed with continuous 6-0 polypropylene suture, while continuous 6-0 and 7-0 monofilament non-absorbable suture were used thereafter. Cardiopulmonary bypass, performed with circulatory arrest and cooling, was restricted to complete repair in groups 2 and 3. The immediate results of surgery were considered satisfactory if a pulsatile flow in the descending aorta was registered by palpation after surgery and the resultant pressure gradient between upper and lower limb was less than 20 mmHg.

**Follow-up**

Length of follow-up ranged from two days to 29.3 years (median 11.9 years). Seven patients were lost to follow-up: 4 patients following RETE and 3 following PA. Follow-up was limited by death in 26 patients. Follow-up ranged from 1-10 years in 115/262 (44%) patients, from 10-20 years in 102/262 (39%) patients and exceeded 20 years in 45/262 (17%) patients. Follow-up included clinical evaluation every three months in the first year after intervention and yearly thereafter. Arm and leg cuff pressures were registered and chest radiography and 2D / continuous-wave echocardiographic Doppler ultrasound studies performed. Follow-up catheterization and angiography were performed in patients suspect for aneurysm formation or recoarctation. An aneurysm was defined as an aortic ratio > 1.5, measuring aortic diameters at the coarctation repair site and thoracic aorta at the level of the diaphragm. A gradient of 20 mmHg and a registered continuation of flow in diastole in echocardiographic Doppler ultrasound studies or blood pressure gradients between upper and lower extremities exceeding 20 mmHg were considered to correspond with recoarctation, requiring reintervention. MRI was performed in patients suspect for aneurysm formation. Recoarctation was treated with repeat surgery or balloon angioplasty after additional angiography.

**Statistical methods**

Test results with a p-value < 0.05 were considered significant in all statistical analyses. Kaplan-Meier survival curves were estimated to determine intervention free probabilities for various groups. Cumulative probabilities in these groups were compared against guidelines using the log rank test. Multivariable Cox regression
analyses were performed for the various outcomes for which sufficient events were encountered. Potential risk factors in these analyses included aortic arch and/or isthmus hypoplasia, era ('73-'87 versus '88-'00), age (less than one month, one month until one year, age from one year) and type of repair (PTFE patch aortoplasty versus RETE).

**Results**

Follow-up of all patients is summarized in figure 1.

**Immediate Results**

Hospital stay varied from six to 22 days (median 11 days). Complications not resulting in death were encountered following 17/255 procedures (6.7%) and included persistent hypertension in 6/255 patients (2.3%). In two of these patients this persistent hypertension could not be treated satisfactory at long-term follow-up, persistent hypertension thereby transferring to late hypertension. False aneurysm formation (two patients), bleeding, arrythmia, chylothorax (two patients), stroke (two patients), atelectasis and thrombus formation in the left atrium were encountered in the rest of these patients.

**Mortality**

Mortality is specified in table 2.

**Table 2.** Mortality specified (n=21/255).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following primary coarctation repair</td>
<td>20</td>
</tr>
<tr>
<td>Postoperatively, following simultaneous correction of VSD</td>
<td>5</td>
</tr>
<tr>
<td>Postoperatively, following simultaneous aortic valvuloplasty</td>
<td>2</td>
</tr>
<tr>
<td>Postoperatively, following unrelated cardiac surgery</td>
<td>9</td>
</tr>
<tr>
<td>Arrythmia during follow-up</td>
<td>1</td>
</tr>
<tr>
<td>Pneumonia during follow-up</td>
<td>2</td>
</tr>
<tr>
<td>Sepsis during follow-up</td>
<td>1</td>
</tr>
<tr>
<td>Following secondary coarctation repair</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
</tr>
</tbody>
</table>

Overall mortality was 21/255 (8.2%). Seven patients died of post-operative complications after primary repair of CoA. This procedure was RETE in 3/7 patients and patch aortoplasty in 4/7 patients. Kaplan-Meier analysis for survival was performed, differentiating groups 1, 2 and 3. The cumulative survival probability at 10 years follow-up was 96.8 ± 1.8% for patients in group 1, 87.0 ± 4.4% in group 2 and 80.6 ± 4.9% in group 3. Log rank test revealed a significant difference between these groups regarding mortality (p=0.001) (figure 2).
Comparison of different types of coarctation repair

Recoarctation

Recoarctation occurred in 53/255 (21%) patients of whom 23/53 (43%) had an RETE and 30/53 (57%) had a patch graft angioplasty. Log rank test revealed no significant difference between both techniques regarding reintervention for recoarctation (p=0.4) (figure 3).

Transverse arch hypoplasia was present in 32/255 (12.5%) patients, isthmus hypoplasia in 36/255 (14.1%) and both conditions in 18/255 (7.1%) patients. Of both conditions, arch hypoplasia was the only for which a significant difference in reintervention was found (log rank test, p=0.030) (figure 4).

Figure 1. Flow diagram of all patients (n=255), managed in a 28-year period. Patients lost-to-follow-up (n=7) are not included.

Figure 2. Kaplan-Meier curves for the probability of survival in patients with native coarctation, managed surgically in different groups with isolated coarctation, associated VSD and associated intracardiac pathology. The numbers of patients available for follow-up at 5-year-intervals are depicted below the graphs.

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Repair was performed at age less than one month in 105/255 (41%) patients, between one month and one year of age in 75/255 (29%) patients and after one year of age in 75/255 (29%) patients. Recoarctation rates were 35/105, 11/75 and 8/75 respectively. A significant difference was found between these age groups regarding recoarctation (log rank test, p<0.001) (figure 5).

**Figure 3.** Kaplan-Meier curves for probability of freedom from reintervention in patients with native coarctation, managed with resection and end-to-end anastomosis (RETE, n=133) and patch graft angioplasty (PA, n=118). The numbers of patients available for follow-up at 5-year-intervals are depicted below the graphs.

**Figure 4.** Kaplan-Meier curves for probability of freedom from reintervention in patients with surgically corrected native coarctation, with (lower plot, n=50) and without (upper plot, n=205) associated arch hypoplasia. The numbers of patients available for follow-up at 5-year-intervals are depicted below the graphs.
Reintervention was performed in all patients with recoarctation. Two patients received RETE, 18 PA and 32 were treated with balloon angioplasty. Re-recoarctation occurred in two patient who had been operated on, these patients underwent secondary balloon angioplasty and RETE. Age less than one month at repair and the presence of transverse arch hypoplasia were the only predictors for recoarctation in multivariable Cox regression analysis. A relative risk of recoarctation for patients less than month of age compared to patients more than one year of age of 6.3 (95% CI: 2.8-14) (p<0.001) was found. No difference between patients from one month to one year of age compared to patients from one year of age was found. The relative risk associated with arch hypoplasia was 2.4 (95% CI: 1.3-4.5) (p=0.006). On the contrary, type of repair, the presence of isthmus hypoplasia, era of repair ('71-'87 versus '88-'00) and associated cardiac pathology were not significant risk factors.

Late hypertension
Late hypertension, defined as blood pressure exceeding 150/90 mmHg in the right arm, measured at regular follow-up assessment, was encountered in 11/255 (4.3%) patients. Late hypertension was encountered in 5/176 (2.8%) patients younger than 1 year of age and in 6/75 (8.0%) patients older than one year of age. Preceding type of coarctation repair had been RETE in 3/11 (27%) and patch aortoplasty in 8/11 (73%). All of these 11 patients needed medication to control this hypertension. Recoarctation had been encountered in 6/11 (55%) patients with late hypertension at any time during follow-up at the time of this review. Hypertension persisted following management of recoarctation in these 6 patients. Age and late hypertension were not found to be related. Patch aortoplasty was associated with a higher rate of late hypertension (log rank test, p<0.03).
Aneurysm formation was encountered in 8/255 (3.1%) patients, all following patch aortoplasty (figure 6). The interval to aneurysm formation varied from four days to 18.6 years (median 12.3). The actuarial 15-year probability of freedom from aneurysm formation following patch aortoplasty was found to be 93 ± 3.1%. The aneurysm that developed within four days postsurgically, was identified to be a false aneurysm. All other aneurysms developed opposite the patch along the medial aspect of the aorta. All these aneurysms developed following procedures involving coarctation ridge resection, performed before 1991. Transverse arch hypoplasia was present in one and both arch and isthmus hypoplasia in two of these patients. Patients in whom aneurysm formation was encountered, underwent successful aneurysm resection and patch graft interpositioning. Neither age, nor transverse arch / isthmus hypoplasia were predictors of aneurysm formation.

Discussion

Immediate results are satisfactory in this series. Few complications were encountered and early mortality occurred in 7/262 (2.7%) patients after primary coarctation repair. The presence of associated cardiac lesions was related to postoperative death in this series. Similar findings have been reported by several authors.4–6 Reported actuarial
survival probabilities at 5 years ranges from 80% to 98% in isolated coarctation, from 62% to 94% for associated VSD and from 15% to 60% for associated complex cardiac anomalies.\(^4\)\(^6\) The actuarial survival probabilities we present for patients with associated complex cardiac anomalies are remarkably high. Different strategies have been advocated to reduce mortality in this group. Our mainstream strategy for coarctation with associated cardiac lesions has been the two-stage repair, with primary correction of the coarctation in 77/93 (83%) patients in groups 2 and 3. 16/93 (17%) patients were managed by a one-stage repair in these groups. Because the one-stage repair was reported to be a safe and effective approach in the preceding decade,\(^6\) we introduced it experimentally at the end of the study period. However, we did not abandon the two-stage repair, since the one-stage repair has not clearly been proven to be favorable.\(^7\)

**Recoarctation and late hypertension**

Echocardiography played a central role in the screening for recoarctation of our patients. When optimal imaging is feasible, being the case in infants and children, the literature supports combined two-dimensional and Doppler color flow echocardiography to image the aortic arch, isthmus, and coarctation site. A sensitivity of 100% for recoarctation can thus be achieved by echocardiography and clinical visit, as was pointed out by Therrien et al..\(^8\) The primary focus in this and most other studies investigating risk factors for recurrent arch obstruction after early coarctation repair, is the relationship between the technique of repair and recoarctation. Type of surgical repair may influence the prevalence of residual or recurrent coarctation by incomplete resection of ductal tissue, suture material and the width of the anastomosis. The possible mechanisms in the process of recoarctation related to these surgical factors consist of inadequate growth of the anastomosis, active fibrosis and narrowing at the anastomotic site, thrombosis at the suture line, and retention of abnormal, possibly ductal, tissue.\(^9\) In the absence of a large, randomized study, superiority of one technique over another is less likely to be demonstrated. On the whole, these studies demonstrate no difference in recoarctation incidence between RETE and subclavian flap,\(^5\)\(^6\) although the probability of recoarctation appears to be higher after simple patch aortoplasty, when patch material has been Dacron or is unspecified.\(^7\)\(^10\) Reported recoarctation rates following PTFE patch aortoplasty, although sparse, are comparable to other techniques.\(^2\)\(^11\)\(^13\) Although more recoarctation following patch aortoplasty has been found in this series (30/118 (25%) patients versus 19/133 (14%) patients for RETE), type of repair was no independent predictor for recoarctation. Furthermore, significant differences could not be established in stratifying patients younger and older than one month of age, although a younger age has been suggested to predispose to recoarctation following PTFE patch repair.\(^7\) The age at operation has been found to be related to the development of recoarctation and, in an inverse manner, to the development of late hypertension. Brouwer and associates determinated the optimal age for elective aortic coarctation repair, for the infant with isolated aortic coarctation who is symptom-free, to be 1.5 years.\(^14\) The risk for recoarctation drops rapidly and levels off at 1.5 years of age and the risk for late hypertension and premature death
increases progressively after that age range.\textsuperscript{14,15} It has been pointed out that the age of 1.5 years may be rather conservative, since recoarctation rates drop below 5\% in current surgical experience with repair performed at age less than one year,\textsuperscript{16} and chronic hypertension developing in as much as 60\% of patients thereafter in other studies.\textsuperscript{17} We therefore stratified patients younger and older than one year of age, but could not find any significant difference in those age groups regarding late hypertension. Nevertheless, this difference was found for type of repair, since patch aortoplasty was associated with a higher late hypertension rate. We hypothesize that in patch aortoplasty the combination of residual ductal tissue and diminished aortic wall compliance are responsible for the occurrence of late hypertension in this group. These phenomena may play a role in recoarctation, in long-term follow-up, also. This may explain the disproportional hazards for recoarctation that were found after five years following different types of repair (figure 2).

\textbf{Arch hypoplasia}
Several reports demonstrated that the anatomy of the aortic arch was a predictor of reintervention for recurrent obstruction after repair.\textsuperscript{9,14} Transverse arch hypoplasia was present in 32/255 (13\%) patients in this study and was demonstrated to be an independent risk factor for recoarctation. The presence of a hypoplastic arch usually increases the left ventricular obstruction created by the coarctation. Nevertheless, a conservative approach towards the hypoplastic arch seems to be justified in most cases, since Siewers et al. have suggested that when the ratio of transverse aortic arch to ascending aorta exceed 0.25, the arch can be expected to grow normally without obstruction and that extended resections should be reserved for those with ratios less than 0.25.\textsuperscript{18}

\textbf{Aneurysm formation}
The interval to aneurysm formation varied from two to almost 19 years, thereby warranting a follow-up for a long enough period. The follow-up protocol for patients in this series, including clinical visits, echocardiography and chest radiography as a screening test and performing an MRI on patients with positive results, was identified as an appropriate strategy in adult patients for both aneurysm formation and recoarctation by Therrien et al.\textsuperscript{8} Since we consider echocardiography more sensitive and specific at lower patient’s ages, we believe that this policy is appropriate for children as well. RETE proved to be superior to PTFE patch aortoplasty most apparently in respect to aneurysm formation. All aneurysm formation in this series, in 8/125 (6.4\%) patients, was encountered following patch aortoplasty. We suggest that indication for PTFE patch aortoplasty, despite its relative easy performance and favorable surgical record must be narrowed, in favor of RETE. Aneurysm formation following patch aortoplasty has been reported on extensively, reported incidence varying between 2\% and 51\%.\textsuperscript{1,19,20} The etiology of aneurysm formation after patch aortoplasty has been attributed to several different factors that are discussed subsequently.
1. Material
There appears to be a striking difference between patch aortoplasty using Dacron grafts, compared to using PTFE. Considerable foreign body giant cell infiltration is demonstrated in Dacron grafts,\(^2^1\) which is not the case with PTFE.\(^1^9\) Probably, this inflammatory response to a Dacron patch makes it more susceptible to aneurysm formation than a PTFE patch, despite Dacron being 20% more compliant, a condition that was considered to be favorable.\(^1^9,2^2,2^3\) The stretching and degeneration of fibers of Dacron, with subsequent dilatation of the material,\(^2^4\) has not been found in PTFE, which does not appear to show any signs of breakdown via chemical or biological processes over time.\(^2^5\) Indeed, a higher incidence of aneurysm formation has been reported following Dacron patch aortoplasty than following repair using PTFE in studies in which both materials were applied.\(^1^3,2^6\) Additionally, no aneurysm formation has been encountered in several reports on using PTFE,\(^2,1^2,1^3\) compared to aneurysm rates between 3% to 22% following patch aortoplasty with Dacron patch.\(^2^0,2^2,2^3\) As regards the use of non-prosthetic material, observations are sparse. Autogenous internal mammary artery was applied as patch material in several studies, with good results in limited follow-up periods.\(^2^7\)

2. Resection of coarctation ridge
The coarctation ridge was excised in the performance of patch aortoplasty in all our patients until 1991. At that time we changed our policy with regard to resecting the coarctation ridge, since violating the intimal aortic layer by resection of the fibrous coarctation membrane has found to be highly related to aneurysm formation in patients in several studies.\(^3^2,3^3\) DeSanto et al. performed patch aortoplasty with and without concomitant intimal excision in dogs experimentally. Aneurysms formed in 8 of 12 animals who had intimal excisions and no aneurysms formed in the control animals.\(^3^8\) All true aneurysm formation we observed, may be caused by ridge resection in patients before the recent era. With a modified patch technique, leaving the coarctation ridge intact, we only encountered one false aneurysm. These observations correspond with Backer’s.\(^3\)

3. Strain and stress
The experimental in-vitro findings of Smaill and associates suggest that synthetic patch aortoplasty may produce increases in wall strain and disproportionate increases in stress adjacent to the patch, associated with changes in local aortic wall geometry that are a direct result of patch implantation.\(^2^9\) The altered hemodynamics that result form the different tensile strengths of a Dacron patch and the posterior aortic wall, with the pulsatile waveform being completely directed to the posterior aortic wall by the inflexible anterior patch, may cause dilatation of the pliable aortic wall.\(^2^0,2^2,2^3\) We do not know of any report on PTFE patch material or modification of the technique of patch aortoplasty, in which these effects were found to be successfully prevented.
4. Age
None of the age categories were found to be risk factor for aneurysm formation in our series. On the contrary, previous reports on Dacron patch aortoplasty supported early surgery.\textsuperscript{1,15} The risk of aneurysm formation was reduced substantially by operating earlier.\textsuperscript{1} Although the aortic wall may be structurally different in infants, thus enabling it to adapt more rapidly to a patch aortoplasty than the aortic wall of patients who undergo surgery at an older age, this may depend on Dacron. According to several authors, prosthetic patch aortoplasty should be abandoned in adolescents and adults, in which high incidence of aneurysm formation was found with advanced patients’ ages. Tubular interpositioning grafting and patch aortoplasty using autogenous arterial wall are proposed as viable alternatives.\textsuperscript{13,20,27} However, there appears to be a minimum age, since Backer and associates found a high recurrence rate in infants less than one month of age, while recoarctation rate was 4/97 in patients from one month of age, following patch aortoplasty with PTFE.\textsuperscript{2}

5. Aortic arch hypoplasia
Different from recoarctation, arch hypoplasia did not reach statistical significance as risk factor for aneurysm formation. In contrast to our findings, Bogaert et al. have identified transverse arch hypoplasia as condition being highly related to aneurysm formation following patch aortoplasty.\textsuperscript{30} They suggest that narrowing of an aortic segment leads to blood flow acceleration and poststenotic turbulence, which may induce aneurysm development in the distal aortic segments. Since aneurysm formation has been encountered following resection and end-to-end anastomosis,\textsuperscript{11} in which the coarcted segment is fully resected, and no “abnormal” patch material is present, wall abnormalities by themselves cannot be (solely) responsible for aneurysm formation, despite statements in several reports.\textsuperscript{10,20,28} Abnormal flow patterns originating in a concomitant hypoplastic arch may have a similar influence on RETE and patch aortoplasty.\textsuperscript{30}

Limitations
The design of this study is limited by the fact that it is retrospective and spans three decades. During this period including patients for RETE and patch aortoplasty has been rather constant. However, both surgical techniques have been improved gradually in course of time, although era (‘71–’87 versus ‘88–’00) was not related to any outcome. Furthermore, patients were not randomized for both techniques. The choice for either RETE or patch aortoplasty was based on the surgeon’s preference in general, but selection bias could not be ruled out in this study design.

Conclusions
The present study findings do not allow extensive conclusions to be drawn in the treatment of coarctation associated with complex intracardiac malformations, for which this association was the most important risk factor. Comparing both surgical techniques, the resection of the coarctation ridge seems to be an important factor with regard to aneurysm formation. Considerable aneurysm formation was found
following patch aortoplasty, combined with coarctation ridge resection. Our findings demonstrate no differences between recoarctation and aneurysm formation with a modified patch aortoplasty. Arch hypoplasia and age less than one month must be considered to predispose recoarctation in patients with coarctation, managed surgically. Although a slightly elevated risk of late hypertension was identified following patch repair, we consider both surgical techniques to be comparable.

References