SURGERY FOR CONGENITAL HEART DISEASE

SURGERY FOR BILATERAL OUTFLOW TRACT OBSTRUCTION IN ELASTIN ARTERIOPATHY

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Objective: A number of patients with Williams syndrome or other forms of elastin arteriopathy have stenoses of pulmonary arteries in addition to supravalvular aortic stenosis. We sought to investigate the effect of the degree of pulmonary arterial stenosis on the prognosis after an operation for supravalvular aortic stenosis to help define the optimal treatment strategy for patients with severe forms of elastin arteriopathy.

Methods: Between 1960 and 1999, 33 patients underwent operations for supravalvular aortic stenosis while having significant stenoses of the pulmonary arteries. We retrospectively reviewed patient charts, obtained current follow-up information, and determined risk factors for survival and reoperation.

Results: Fifteen patients with moderate right-sided obstructions (confirmed by pulmonary artery Z-scores and right ventricular/descending aortic pressure ratio) underwent operations for supravalvular aortic stenosis only. Eighteen patients had more severe right-sided obstructions and underwent surgical relief of pulmonary arterial stenoses or right ventricular outflow tract obstruction in addition to operations for supravalvular aortic stenosis. Eight patients had undergone preoperative balloon dilations of stenotic pulmonary arteries. There were 6 early deaths and 1 late death in our series. Survival at 10 and 20 years was 76% (70% confidence interval, 68%-84%) and freedom from reintervention was 59% (70% confidence interval, 46%-71%) at 10 years and 49% (70% confidence interval, 35%-62%) at 20 years. Multivariate analysis revealed that patients with a right ventricular/descending aortic pressure ratio of 1.0 or more were at higher risk for reintervention but not for death.

Conclusions: Surgical treatment of pulmonary artery obstructions in elastin arteriopathy is palliative but, in conjunction with balloon dilation of peripheral pulmonary arteries, offers good long-term survival to patients with the severest form of elastin arteriopathy. (J Thorac Cardiovasc Surg 2000;120:755-63)

The underlying cause for congenital supravalvular aortic stenosis (SVAS) in patients with Williams syndrome, familial SVAS, and probably also sporadic SVAS has been identified as a chromosomal microdeletion at 7q11.23, including the elastin gene.[1] The resulting decrease in elastin expression during development

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is associated with an increased number of elastin lamellae and excessive accumulation of collagen and smooth muscle cells in the vascular wall, resulting in formation of severely thickened and rigid arterial vessels.[2-4] This elastin arteriopathy is not a localized process but rather a generalized disease of both the systemic and pulmonary arterial systems.[5-7] Although in many patients with SVAS only the aortic obstruction is of clinical relevance, obstructions of the pulmonary vasculature are frequently observed.[8-11] Peripheral pulmonary arterial stenosis has long been acknowledged as part of Williams syndrome, and central pulmonary artery stenosis is often found.[12] Patients with elastin arteriopathy may also have pulmonary artery stenoses without having relevant SVAS.[9,13] Localized supravalvular pulmonary stenosis has also been described,[14,15] although it is the least frequent type of pulmonary artery stenosis in elastin arteriopathy. Depending on the degree of stenosis, right ventricular pressure overload and biventricular hypertrophy may develop. Several reports indicate that in the natural course of the disease, the severity of pulmonary artery stenoses, and thus right ventricular pressure load, decrease throughout childhood and adolescence.[10,13,16-18] However, there are a number of patients with severe pulmonary artery stenoses who require surgical treatment for SVAS while also having significant right ventricular pressure overload, and these patients may have a higher operative risk.

We have previously reported our institutional experience with surgical treatment of SVAS with respect to aortic valve function.[11] In this study we sought to (1) examine the nature of pulmonary artery stenosis in these patients in greater detail, (2) determine the effect of different degrees of pulmonary artery stenosis on the prognosis after surgical treatment of SVAS, and (3) help define the optimal treatment strategy on the basis of the results of surgical relief of pulmonary artery obstructions as part of a generalized elastin arteriopathy.

Methods

This study is confined to patients who underwent an operation for SVAS at Children's Hospital Boston between 1960 and 1999 and had concomitant pulmonary artery stenoses indicating generalized elastin arteriopathy. Patients operated on before August 1998 were also included in a study that analyzed the results of different techniques for reconstruction of the aortic root in SVAS.[11] The patients' charts were reviewed, and questionnaires were sent to physicians and cardiologists. All available reports of cardiac catheterization, echocardiography, and lung perfusion scans were reviewed. Patients or parents were contacted and sent a questionnaire when no recent follow-up information was available. The protocol was approved by the Children's Hospital Institutional Review Board. The follow-up period ranged from between 5 months and 34 years (mean 9.2 years), and cross-sectional follow-up was complete for all patients as of June 1999.

Hemodynamic and morphometric measurements. Data were obtained during routine clinical follow-up and reviewed retrospectively. Preoperative left ventricular and aortic pressure measurements were performed by cardiac catheterization in 31 patients; the left ventricular–aortic pressure gradient at follow-up was assessed by Doppler echocardiography in 16 patients and cardiac catheterization in 13. Right ventricular pressure was measured by means of preoperative cardiac catheterization in 27 patients. Right heart catheterization during follow-up was performed in 13 patients (3.2 ± 2.8, median 1.5 years postoperatively). In 15 patients right ventricular pressure at follow-up was derived from the peak velocity of the tricuspid regurgitation jet, as measured by Doppler echocardiography (performed 6.9 ± 3.1, median 5.4 years postoperatively). The right ventricle/descending thoracic aorta (RV/AoDT) pressure ratio was calculated to assess right ventricular pressure load. The pulmonary artery diameter was measured on anteroposterior angiograms in 24 patients preoperatively and in 13 patients at follow-up. Two-dimensional echocardiography was used to measure the diameter of the central pulmonary arteries at follow-up in 16 patients. Z-scores of pulmonary artery size for a given body surface area were calculated by use of the diameter measured midway between the origin and first branching point. Calculations were based on the normal ranges reported by Sievers and colleagues[19] for measurements obtained from angiograms and on an institutional database representative of the local patient demographics for echocardiographic measurements.[20]

Definitions. *Central pulmonary artery stenosis* was defined as greater than 50% narrowing in diameter of the main, left, or right pulmonary artery, as demonstrated by angiography or echocardiography. *Peripheral pulmonary artery stenosis* was defined as greater than 50% narrowing distal to the pulmonary artery branching point at the hilum, as demonstrated by angiography. *Diffuse pulmonary artery stenosis* was defined as an angiographically diagnosed bilateral hypoplasia involving the central and peripheral pulmonary arteries. *Discrete SVAS* was defined as an hourglass-shaped narrowing of the aorta at the level of the sinutubular junction. A tubular narrowing involving the ascending aorta or beyond was termed *diffuse*.

Statistical analysis. Estimated rates of survival and freedom from reoperation with 70% confidence intervals (CI) were determined by the Kaplan-Meier product-limit method, and survival curves were compared by the log-rank test. The Cox proportional-hazards regression model was used to establish the variables independently associated with each outcome, with risk measured by the adjusted hazard ratio.[21] Variables tested were as follows: surgical, interventional, or both types of treatment of pulmonary artery stenosis; type of SVAS (diffuse or discrete); and presence of diffuse pulmonary artery stenosis. Age at the time of operation, year of

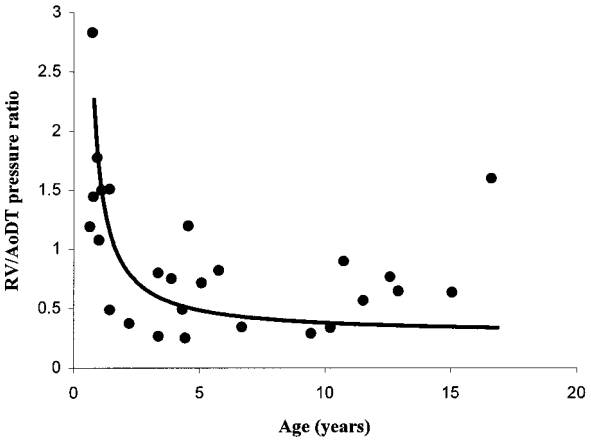

Fig 1. Right ventricular/descending aortic *(RV/AoDT)* pressure ratio as a function of age at investigation. Measurements were obtained by means of preoperative right and left heart catheterization in 25 patients. Nonlinear regression analysis revealed a negative correlation between the RV/AoDT pressure ratio and patient age ($R = 0.65$, $R^2 = 0.43$, $P = .0003$).

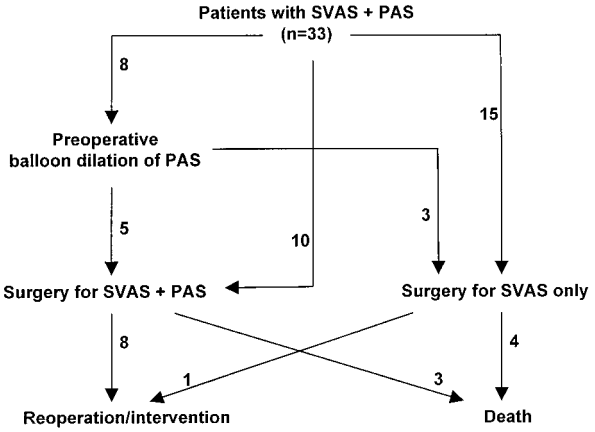

Fig 2. Flow chart indicating the number of patients associated with a respective treatment or outcome. SVAS, Supravalvular aortic stenosis; PAS, pulmonary artery stenosis.

operation, and RV/AoDT pressure ratio were investigated as continuous variables. A forward stepwise selection procedure was used to build the final multivariate models by means of the variables stated above. Hemodynamic and morphometric variables were evaluated by the Kolmogorov-Smirnov test to ascertain whether the measurements follow a normal distribution. For variables having a skewed distribution, the Mann-Whitney *U* test was used for between-group comparisons, and the Wilcoxon signed-rank test was used for comparisons of preoperative and follow-up data. Variables following a normal distribution (including Z-scores) were analyzed by means of the appropriate parametric *t* test. The correlation between patient age and the RV/AoDT pressure ratio was tested by fitting the data to a nonlinear decay function of the first order. Data were analyzed with the SPSS software package (version 9.0; SPSS Inc, Chicago, Ill).

Results

Thirty-three patients with SVAS and pulmonary artery stenosis underwent operations at our institution. Thirteen (39%) of the patients were male, and 20 (61%) were female. Ages at operation ranged between 6 months and 16 years (mean 5.7 years; median 3.7 years). In 23 (70%) patients a diagnosis of Williams syndrome was made by a medical geneticist and supported by fluorescence in situ hybridization analysis of a deletion on chromosome 7q11.23. In 5 (15%) patients a familial history of SVAS, generalized arteriopathy, or both, was known, and the remaining 5 (15%) patients were classified as sporadic cases. Associated cardiovascular anomalies included patent ductus arteriosus (n = 1), atrial septal defect (n = 1), small muscular ventricular septal defect (n = 1), and stenosis of the left main coronary artery (n = 1). Systemic arterial stenoses were demonstrated in 12 (36%) patients and involved renal arteries (n = 6) and aortic arch branches (n = 9). Six patients had previously undergone cardiovascular procedures other than balloon dilations of pulmonary artery stenoses, including repair of aortic coarctation (n = 4), division of a patent ductus arteriosus (n = 1), and balloon dilation of a stenotic left carotid and innominate artery.

Twenty (61%) patients were in New York Heart Association functional class II to IV. One patient had repeated syncopal episodes. Electrocardiographic evidence, echocardiographic evidence, or both, of significant biventricular hypertrophy was present in 28 (85%) patients. Two patients underwent emergency operations while receiving cardiopulmonary resuscitation after cardiac arrest, one during diagnostic coronary angiography and one during induction of anesthesia.

Left ventricular–aortic pressure gradients ranged between 35 and 120 mm Hg, and right ventricular pressures ranged between 30 and 200 mm Hg. The RV/AoDT pressure ratios ranged between 0.3 and 2.8 (mean 0.9; median 0.75) and was greater than 1.0 in 9 patients. There was a nonlinear correlation between age at the time of the investigation and the RV/AoDT pressure ratio (Fig 1). Stenosis of the proximal right pulmonary artery was demonstrated in 26 (79%) patients, and stenosis of the left pulmonary artery was demonstrated in 20 (61%) patients. Peripheral pulmonary artery stenosis was present in all patients, usually involving more than one lobar or segmental pulmonary

Table I. *Preoperative measurements in patients with elastin arteriopathy, SVAS, and PAS*

	Total (n = 33)	*PAS not treated (n = 15)*	*PAS treated (n = 18)*
Age (y) at operation, median (range)	3.7 (0.5-16)	9.4 (1.4-16)	2.6 (0.5-6)*
LV–Ao pressure gradient (mm Hg)	85 ± 40	91 ± 42	75 ± 24
RV pressure (mm Hg)	81 ± 49	53 ± 26	104 ± 45*
RV/AoDT pressure ratio, median (range)	0.75 (0.3-2.8)	0.52 (0.3-1.6)	1.19 (0.7-2.8)*
Elevated RA pressure (>10 mm Hg), n	5	1	4
Diameter of RPA (Z-score)	–2.1 ± 1.5†	–1.1 ± 0.9	–3.4 ± 0.6*†
Diameter of LPA (Z-score)	–1.3 ± 0.8†	–0.9 ± 0.3†	–1.6 ± 1*
Right PAS (n)	27	12	15
Left PAS (n)	21	11	10
Diffuse PAS (n)	12	7	5
Pulmonary valve stenosis (n)	9	2	7
Supravalvular pulmonary stenosis (n)	4	1	3
RV infundibular stenosis (n)	1	0	1
Lung perfusion mismatch (n)	7	NA	7

Data are shown for the entire cohort *(Total)* and separately for patients in whom treatment of both SVAS and pulmonary artery stenosis was indicated *(PAS treated)* and patients who underwent operations for SVAS only *(PAS not treated)*. Data are expressed as means ± SD where shown. *SVAS,* Supravalvular aortic stenosis; *PAS,* pulmonary artery stenosis; *LV-Ao,* left ventricular–aortic; *RV,* right ventricular; *RV/AoDT,* right ventricular/descending thoracic aorta; *RA,* right atrial; *RPA,* right pulmonary artery; *LPA,* left pulmonary artery; *NA,* Not applicable.

*$P < .05$ compared with *PAS not treated* (2-sample *t* test).

†$P < .05$ compared with the normal population mean of zero (1-sample *t* test).[19,20]

artery. Diffuse pulmonary artery stenosis was present in 12 (36%) patients. Pulmonary valve stenosis was found in 9 patients, and a supravalvular narrowing of the main pulmonary artery was found in 4. In 1 patient stenosis of the right ventricular infundibulum was noted in addition to a small pulmonary valve and stenoses of both the right and left pulmonary arteries. Lung perfusion scans were performed in 14 patients with more severe pulmonary artery stenosis and demonstrated a marked perfusion mismatch in 7. As indicated by elevated right atrial pressure (>10 mm Hg), 5 patients had evidence of right ventricular failure. A systemic venous oxygen saturation of less than 50%, which indicated insufficient systemic perfusion, was found in 1 patient.

To illustrate the severity of the disease in patients who were assigned to relief of right-sided obstructions, Table I shows preoperative measurements grouped into those undergoing or not undergoing treatment for pulmonary artery stenosis. In 15 patients SVAS was relieved, but pulmonary artery stenoses were not treated. These patients had less severe pulmonary artery obstructions as demonstrated by lower RV/AoDT pressure ratios and higher pulmonary artery Z-scores, except 1 patient who was operated on for SVAS in 1960 with a RV/AoDT pressure of 1.6 but who did not undergo relief of pulmonary artery stenosis. Eight patients underwent 1 or more percutaneous balloon dilations of pulmonary artery stenoses before surgical relief of SVAS. In 7 of these procedures, the diameter of the vessel was enlarged and the gradient across the stenosis decreased, as assessed immediately after balloon dilation. Fifteen patients underwent surgical augmentation of stenotic pulmonary artery stenoses together with operations for SVAS, and 2 of those patients also had an intraoperative balloon angioplasty (Fig 2).

Operative technique. Techniques for augmentation of the aortic sinutubular junction and ascending aorta were described in detail in our previous report.[11] Central pulmonary arterial stenoses were augmented by insertion of a pericardial patch after longitudinal incision of the vessel in 9 patients. In 1 patient a proximal stenosis of the right pulmonary artery was excised followed by end-to-end anastomosis of the artery. Long-segment stenoses of both the right and left pulmonary arteries were treated by insertion of a pericardial patch throughout both pulmonary arteries from the right to the left hilum in 4 patients, in 2 of them in the form of a Y-shaped patch to enlarge the main pulmonary artery also. In 2 patients an inverted Y-shaped patch was inserted in the main pulmonary artery and the right and left facing sinuses to augment supravalvular pulmonary stenosis. In 3 patients with multilevel right ventricular outflow tract obstruction, a transannular patch was inserted after incision of the infundibulum, pulmonary root, and main pulmonary artery. In 1 patient with complex right ventricular outflow tract obstruction, a right ventricle–pulmonary artery homograft conduit was implanted in an orthotopic position supplemented by pericardial patches enlarging the right ventricular infundibulum and both branch pulmonary arteries. Peripheral pulmonary artery stenoses were treated by intraoperative balloon angioplasty in 2 patients.

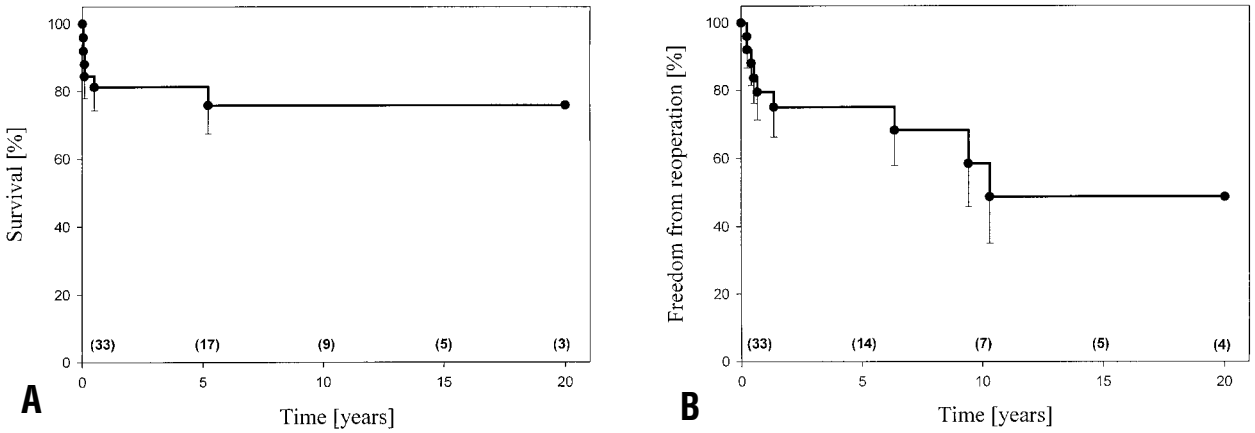

Fig 3. Kaplan-Meier estimated 20-year overall survival **(A)** and freedom from reoperation or intervention **(B)**. *Error bars* indicate the lower 70% CI. Number of patients at risk are shown in *parentheses*.

Reoperations or interventions. One patient was reoperated on for restenosis at the distal end of the aortic patch, and several procedures were performed for recurrent or residual pulmonary artery stenosis. After patch enlargement of the right pulmonary artery, early restenosis developed in 1 patient at the site of the pericardial patch, and the patch was replaced 1 year after the initial operation. The patient who underwent replacement of the right ventricular outflow tract by a homograft had obstruction of the homograft with a gradient of 50 mm Hg after 6.5 years. Attempted balloon dilation of the stenotic homograft failed, and the stenosis was relieved by insertion of a generously sized preclotted Dacron patch. In 6 patients, one or more balloon dilations of pulmonary artery stenoses were performed during the follow-up period, in 1 case including placement of an intravascular stent. Overall freedom from reoperation or intervention estimated by the Kaplan-Meier method was 75% (70% CI, 66-84%) at 5 years, 59% (70% CI, 46-71%) at 10 years, and 49% (70% CI, 35-62%) at 20 years (Fig 3, *B*). Multivariable analysis revealed that patients with a preoperative RV/AoDT pressure ratio of 1.0 or greater were at higher risk for reoperation or intervention (Fig 4, *A*). Six of the 9 patients who required reoperation had an RV/AoDT pressure ratio of 1.0 or greater, and 20 of the 23 patients not requiring reoperation had a pressure ratio of less than 1.0 (adjusted hazard ratio, 7.4; 70% CI, 3.6-14.9; $P = .01$). Cox regression also revealed that patients with pulmonary artery stenoses necessitating surgical or interventional treatment at the time of operation for SVAS were more likely to undergo reoperation or intervention during follow-up (adjusted hazard ratio, 4.0; 70% CI, 1.5-10.8; $P = .03$). Operation after 1987 also proved an independent risk factor for reoperation or intervention (hazard ratio, 1.3; 70% CI, 1.1-1.6; $P = .02$), which may be influenced by the fact that interventional treatment options for patients with severe pulmonary artery stenosis were not available before.

Mortality. There were 6 early deaths in our series. Neither of the above-mentioned patients who underwent emergency operations after cardiac arrest was successfully weaned from bypass. Two other patients had biventricular failure with low cardiac output and were supported by extracorporeal membrane oxygenation or a biventricular assist device, respectively. Ventricular function did not recover, and both patients died after circulatory support was discontinued. Two patients earlier in the series died after cardiac arrest when no mechanical support was available. One patient with diffuse pulmonary artery stenosis, mild right pulmonary artery stenosis, an aortic gradient of 100 mm Hg, and an RV/AoDT pressure ratio of 0.64 died 5 years after single patch enlargement of the supravalvular aorta. Three years postoperatively, he had a residual left ventricular gradient of 80 mm Hg and moderate right ventricular hypertension (58 mm Hg; RV/AoDT pressure ratio, 0.75), but he refused further surgical treatment. An autopsy was performed, and the death was attributed to left ventricular failure. Overall survival estimated by the Kaplan-Meier method was 81% (70% CI, 78-92%) at 5 years and 76% (70% CI, 68-84%) at 10 and 20 years (Fig 3, *A*). There was no correlation between the RV/AoDT pressure ratio and survival. Because an RV/AoDT pressure ratio proved a risk factor for reoperation or intervention, we also plotted survival for these subsets of patients to demonstrate

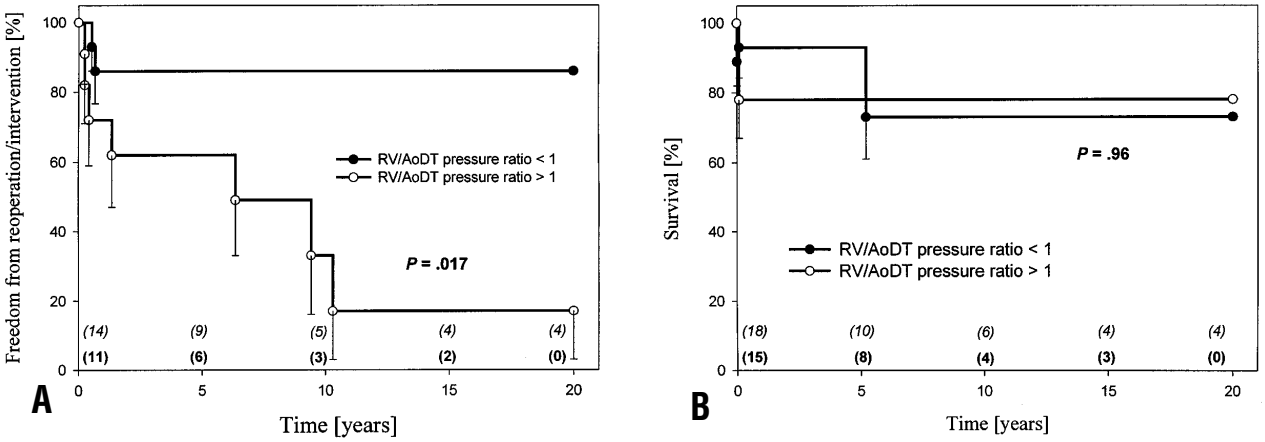

Fig 4. Kaplan-Meier estimated 20-year freedom from reoperation or intervention **(A)** and survival **(B)** for patients with elastin arteriopathy and suprasystemic right ventricular pressure (RV/AoDT pressure ratio > 1) and patients with an RV/AoDT pressure ratio of less than 1. *P* values shown on the plots were calculated by the log-rank test. *Error bars* indicate the lower 70% CI. Numbers of patients at risk are shown in *parentheses*; the group with an RV/AoDT pressure ratio of less than 1 is shown in *italics*, and the group with an RV/AoDT pressure ratio of greater than 1 is shown in **boldface**.

Table II. *Postoperative measurements in patients with elastin arteriopathy, SVAS, and PAS*

	Total (n = 27)	*PAS not treated (n = 12)*	*PAS treated (n = 15)*
LV-Ao pressure gradient (mm Hg)	15 ± 9	16 ± 9	13 ± 8
RV pressure (mm Hg)	64 ± 21	63 ± 17	64 ± 15
RV/AoDT pressure ratio, median (range)	0.57 (0.2-1.1)	0.59 (0.2-1.1)	0.54 (0.4-0.8)
Elevated RAP (>10 mm Hg), n	2	0	2
Diameter of RPA (Z-score)	–1.1	–1.0 ± 0.7	–1.1 ± 0.4
Diameter of LPA (Z-score)	–0.4	–0.5 ± 0.2	–0.4 ± 0.5
Lung perfusion mismatch (n)	1	NA	1

Data are shown for the entire cohort *(Total)* and separately for patients in whom treatment of both SVAS and PAS was indicated *(PAS treated)* and patients who underwent operations for SVAS only *(PAS not treated)*. Data are expressed as means ± SD. *SVAS*, Supravalvular aortic stenosis; *PAS*, pulmonary artery stenosis; *LV-Ao*, left ventricular–aortic; *RV*, right ventricular; *RV/AoDT*, right ventricular/descending thoracic aorta; *RAP*, right atrial pressure; *RPA*, right pulmonary artery; *LPA*, left pulmonary artery; *NA*, Not applicable.

*$P < .05$ compared with *PAS not treated* (2-sample *t* test).

†$P < .05$ compared with the normal population (1-sample *t* test).[19,20]

that survival was not different for these patients (Fig 4, *B*). Multivariate analysis identified none of the other tested variables as risk factors of death.

Hemodynamics and symptoms at follow-up. The left ventricular–aortic pressure gradients ranged between 0 and 65 mm Hg. Right ventricular pressure ranged between 24 and 100 mm Hg, and the RV/AoDT pressure ratio ranged between 0.3 and 1.1. Both preoperative and postoperative RV/AoDT pressure ratios were available for 20 patients (Fig 5). The RV/AoDT pressure ratio decreased in 11 (100%) of 11 patients who underwent treatment for pulmonary artery stenosis and in 5 (59%) of 9 patients who underwent operations for SVAS only. Five patients had an RV/AoDT pressure ratio of greater than 0.7 at follow-up. Two patients were in New York Heart Association functional class II, 2 patients had occasional chest pain on exertion, and a further 2 patients had a syncopal episode, both of unknown cause.

Discussion

We have previously reported our institutional experience with surgical treatment for SVAS, and 41% of these patients had concomitant stenoses of the right ventricular outflow tract, pulmonary arteries, or both.[11] The presence of a right-sided obstruction was not a risk factor for survival or reoperation. Given that the severity of the pulmonary artery stenoses varies markedly, we performed the present study to analyze the surgical results in this subset of patients in greater detail. In 15

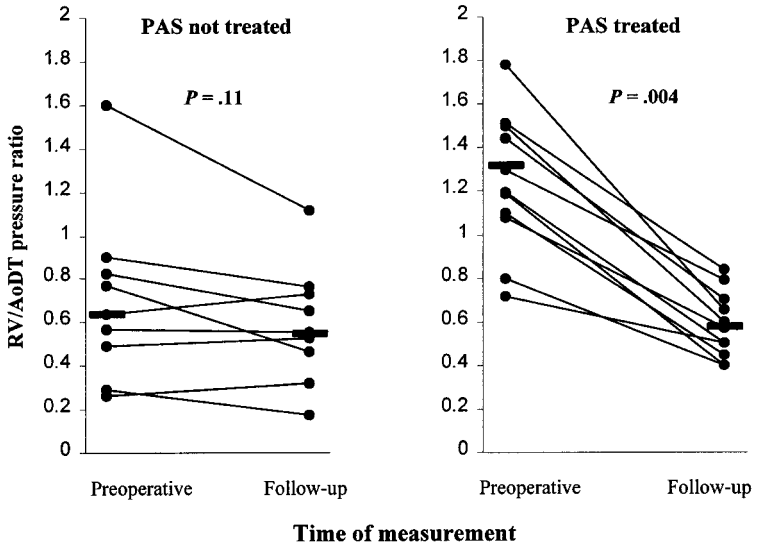

Fig 5. RV/AoDT pressure ratio preoperatively and at follow-up. *PAS not treated,* Patients who underwent operations for SVAS only; *PAS treated,* patients who underwent operations for both SVAS and pulmonary artery stenosis. The *P* values displayed on the plots were determined by the paired Student *t* test. Follow-up measurements were obtained 4.7 ± 2.9 years postoperatively (median 3.4 years). *Horizontal bars* indicate median.

patients with bilateral stenoses, treatment of right-sided obstructions was not indicated at the time of operation for SVAS, and none of these patients has required reoperation or intervention. The majority of these patients had milder stenoses initially, and right ventricular pressure load spontaneously decreased in 5 of 9 during follow-up.

The opposite end of the spectrum is represented by patients with severe, generalized, obstructive arteriopathy, for whom the anatomic term *macaroni arteriopathy* was coined. They usually have severe biventricular pressure overload, are at exceedingly high risk of myocardial ischemia, and are often deemed untreatable. A large proportion of the patients who underwent treatment of right-sided stenoses are very close to this end of the spectrum. In addition to significant SVAS requiring surgical reconstruction, the majority of these patients had multiple pulmonary artery stenoses or complex right ventricular outflow tract obstruction, resulting in suprasystemic right ventricular pressure (Fig 6). They were referred for surgical treatment at a significantly younger age than patients with milder stenoses. Our selective approach combining preoperative balloon dilation of peripheral pulmonary artery stenoses and surgical relief of central stenoses at the time of operation for SVAS resulted in a 20-year survival of 79% (Fig 4, *B*), which is similar to the previously reported overall survival of patients with SVAS.[11] We consider it important to reduce right ventricular pressure overload before or at the time of operation for SVAS because the ischemic injury imposed on such severely hypertrophied hearts during the repair can have deleterious effects in the presence of excessively high afterload. The hypertrophied myocardium is more susceptible to ischemia,[22,23] and in addition to our own experience, the literature shows several reports of patients with elastin arteriopathy who had right ventricular failure after the operation for SVAS.[11,17] Eight patients had previously undergone balloon dilations of pulmonary arteries,[24-27] so that in combination with surgical enlargement of more proximal stenoses, right ventricular pressure load was reduced before or at the time the heart was subjected to global ischemia for repair of SVAS.

Some of these patients may still require interventional treatment of residual, recurrent, or newly developed pulmonary artery stenoses after the initial operation. It is not clear whether balloon angioplasty of pulmonary arteries in elastin arteriopathy is as effective as dilation of other forms of pulmonary artery stenosis. The decreased elasticity of the arteries may increase the risk of rupture during balloon inflation, and smooth muscle proliferation in elastin arteriopathy may result in earlier restenosis. We therefore aim at a generous patch enlargement of pulmonary artery stenoses in elastin arteriopathy whenever stenoses are proximal to the lung hilum and as such accessible to the surgeon.

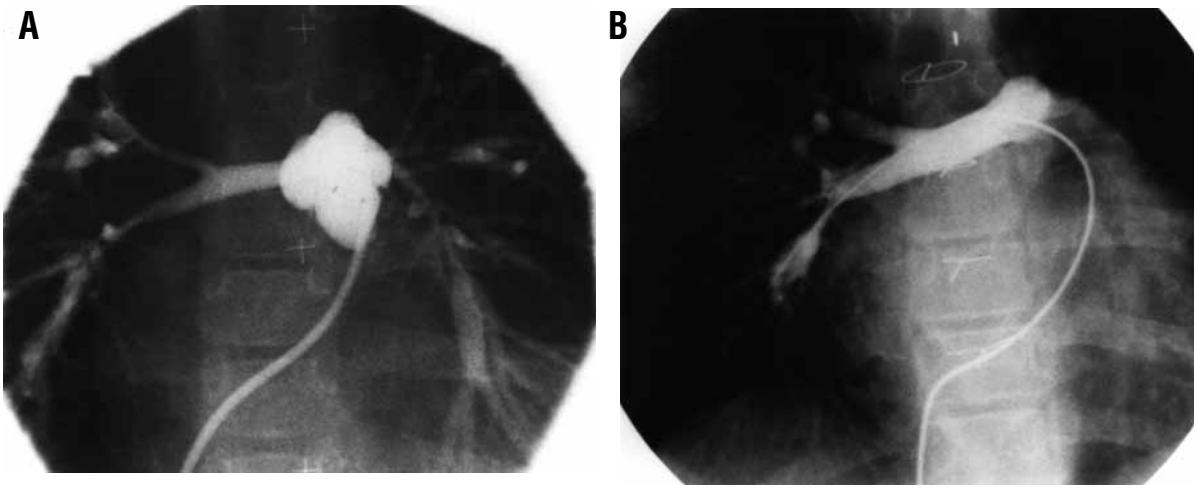

Fig 6. A, Pulmonary angiogram (right pulmonary artery) of a patient with diffuse pulmonary artery stenosis (age 3.7 years) at the time of diagnosis (RV/AoDT pressure ratio, 1.2; Z-scores: right pulmonary artery, –3.9; left pulmonary artery, –2.1). The patient underwent preoperative balloon dilation of several lobar pulmonary arteries followed by an operation for SVAS and insertion of a pericardial patch in the central right and left pulmonary arteries. **B,** Pulmonary angiogram of the same patient 10.2 years postoperatively. The central pulmonary arteries are of good size (Z-scores: right pulmonary artery, –0.6; left pulmonary artery, –0.2) but peripheral pulmonary artery stenosis persists. Multiple balloon dilations of peripheral pulmonary arteries were subsequently performed with angiographic and hemodynamic improvement (RV/AoDT pressure ratio, 0.5).

Several reports have suggested that the severity of pulmonary artery stenoses in Williams syndrome decreases over time.[10,13,16-18] However, it is notable that very few of the patients included in these reports initially had suprasystemic right ventricular pressure. A possible explanation may be that these patients rarely reach the age for a follow-up examination without undergoing treatment or dying. We observed improvement of right ventricular pressure overload without treatment in 5 patients. Because serial hemodynamic assessments are frequently not available, in some reports the correlation between patient age or body surface area and severity of pulmonary artery stenoses has been used to support the concept of improvement of pulmonary artery stenosis over time.[13,17] We also found a correlation between age and severity of pulmonary artery stenosis (assessed by RV/AoDT pressure ratio). However, as opposed to waiting for spontaneous improvement of pulmonary artery stenoses, we advocate an early relief of right-sided obstructions to minimize the risk of an operation when relief for SVAS is indicated.

Limitations of the study. As a retrospective study based on a small number of patients with complete functional follow-up but incomplete hemodynamic and morphometric data, the statistical power of this analysis is certainly limited. The patient selection was based on clinical criteria (undergoing an operation for SVAS while having significant pulmonary artery stenosis) that are likely to influence the clinical course of the patients. However, as we and others have pointed out previously, the underlying disease is probably identical in all patients with congenital SVAS. Furthermore, we did not include patients with the same etiology who underwent interventional treatment of right-sided obstructions only.

Conclusion

In summary, we conclude that an individualized, combined, cardiac surgical and interventional approach to children with the severe forms of elastin arteriopathy, biventricular pressure overload, and suprasystemic right ventricular pressure results in favorable long-term survival. However, generalized arteriopathy with severe bilateral outflow tract obstruction and suprasystemic right ventricular pressures remains a surgical challenge. Surgical treatment is palliative and requires careful follow-up examinations and frequently additional pulmonary balloon angioplasty to ensure successful long-term outcome.

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