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Balloon angioplasty in aortic coarctation: A multicentric study in Mexico

Balloon angioplasty in aortic coarctation: a multicentric study in Mexico

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Summary

Objectives: To analyze immediate and long-term results of balloon dilation for aortic coarctation in a three-center experience in Mexico, and to determine factors associated with increased risk.

Background: Results demonstrated that the procedure is effective and safe, however its use in some groups is still controversial, specially in neonates and infants. **Methods:** In a ten-year period, 333 patients with aortic coarctation on underwent balloon dilation with an immediate success rate of 93.7% and a major complication incidence of 1.8%. Of the total cohort, 272 patients were followed for a period of 24.3 ± 20 months. Demographic and procedural data were analyzed to determine factors related to a poor outcome or to sustained high blood pressure. **Results:** Cox regression analysis found age (risk ratio 3.42 p = 0.000l), isthmic hypoplasia (risk ratio 4.64, p < 0.0001), and post-dilation gradient (risk ratio 2.19, p = 0.0113) as independent risk factors for a follow-up event, mainly restenosis. Age at dilation was the only independent factor related to sustained hypertension with a seven-fold increase in the risk. **Conclusions:** Balloon dilation is an effective and safe alternative to treat aortic coarctation. Patients younger than one year of age, with severe isthmic hypoplasia and a post-dilation gradient > 20 mmHg have the highest risk to develop an event in the follow-up period. When the dilation procedure is performed in patients older than 10 years of age,

Resumen

ANGIOPLASTÍA CON BALÓN EN LA COARTACIÓN AÓRTICA. ESTUDIO MULTICÉNTRICO EN MÉXICO

Objetivo: Analizar los resultados inmediatos y a largo plazo de la dilatación con balón en coartación aórtica realizada en tres diferentes centros hospitalarios en la ciudad de México, y determinar los factores asociados que incrementan los riesgos. **Antecedentes:** Los resultados del procedimiento han demostrado ser efectivos y de sencilla realización, sin embargo, algunos grupos se han considerado como controversiales, especialmente en neonatos e infantes. **Métodos:** En un periodo de diez años, 333 pacientes con coartación aórtica fueron sometidos a dilatación con resultados inmediatos exitosos en un 93.7% de los casos y una incidencia de complicaciones mayores de 1.8%. Del total del grupo 272 pacientes tuvieron seguimiento durante 24.3 ± 20 meses. Fueron analizados los datos demográficos y del procedimiento para determinar los factores relacionados con una mala evolución o una hipertensión arterial sistémica sostenida. **Resultados:** El análisis de regresión de Cox encontró que la edad (índice de riesgo 3.42, p = 0.0001), hipoplasia del istmo (índice de riesgo 4.64, p < 0.001), y gradiente post-dilatación (índice de riesgo 2.19, p = 0.0113) son factores de riesgo independientes para un evento subsecuente, principalmente re-estenosis. La edad, al momento de la dilatación fue el único factor independiente para hipertensión sostenida, con un

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and specially those older than 20 years, the probability that they remain or develop high blood pressure is increase.

incremento de siete veces en el riesgo. **Conclusiones:** La dilatación con balón es un tratamiento alternativo, efectivo y seguro para la coartación aórtica. Los pacientes menores de un año de edad con hipoplasia severa del istmo y un gradiente post-dilatación tienen un mayor riesgo de desarrollar un evento subsecuente en el seguimiento. Cuando el procedimiento es realizado en pacientes mayores de 10 años de edad y principalmente en mayores de 20 años, la probabilidad de que ellos permanezcan con hipertensión arterial o la desarrollen es mayor.
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Key words: Aortic coarctation. Balloon dilation. Isthmic hipoplasia.
Palabras clave: Coartación aórtica. Angioplastía. Estenosis.

Introduction

The first balloon angioplasty in a newborn with aortic coarctation was accomplished in 1982,[1] since then, the experience of several groups in the treatment of native aortic coarctation and of recurrent post-surgical coarctation has been published.[2-10] Through results have demonstrated that the procedure is effective and safe, the interventional treatment of aortic coarctation is still controversial.[11] Recent reports have suggested similar or slightly better results with balloon dilation of native aortic coarctation than with surgical treatment.[12] Some groups favor surgical treatment, but the time for intervention of elective cases is still in discussion, among groups that are in favor of balloon dilation, some recommend dilation after certain age, since it has been observed a higher restenosis rate in the neonatal and infant groups.

Our objective is to show the immediate and long-term results of balloon angioplasty for aortic coarctation in a three-center experience in Mexico, and to determine possible risk factors for a poor outcome.

Material and methods

Study population

Balloon dilation of aortic coarctation has been performed in Mexico since 1988, and in a ten-year experience the three centers have performed this procedure in 333 patients. Data were obtained in all cases from their clinical records. General demographic data, procedural determinants and hemodynamic variables were obtained in all cases. Of the total cohort, 272 (81.7%) cases had valid follow-up data for analysis *(Table I).*

The degree of aortic hypoplasia was classified in 272 patients, according to the relationship between the diameter of the isthmus divided by the diameter of the aorta at the level of the diaphragm or at the level of the emergence of the left carotid artery in three degrees, without hypoplasia, when the ratio was ≥ 1; mild to moderate, with ratios between 0.67 and 0.99, and severe, ≤ 0.66. Success of the procedure was defined as a 50% reduction of the pre-dilation gradient or a residual gradient below 20 mmHg and without major complications.

Complications were divided as major, minor, failure of the procedure and incidents. Major complications were those that caused death, permanent disability or severe hemodynamic dysfunction. Minor complications were those that required treatment, but result without sequel. Failure of the procedure included abandonment by technical problems or an unsuccessful procedure. Incidents were defined as episodes without transcendence that were solved favorably, as balloon rupture, transient cardiac arrhythmias, etc.

Dilation procedure

The balloon angioplasty procedure was performed through puncture of the femoral artery in all cases as previously described.[13-18] All patients were heparinized with 100 u/kg. The coarctation was crossed with a flexible guide wire and a multipurpose catheter; in 3-year-old and older children a pigtail catheter (USCI, Schneider or Cordis) was advanced through an exchange J-tip wire (Super Stiff, Meditech, Boston Scientific Corp.) to perform the pressure measurements and aortography. In younger children this was done through a multipurpose or a cut pigtail catheter. Systolic, diastolic and mean pressures were recorded in the left ventricle and in ascending and descending aorta and the gradient across the coarctation was determined. Aortogra-

Table I. Preprocedural data.

Variable	Total group N = 333 (range or %)	Follow-up group N = 272 (range or %)	p
Age (years)	9.74 ± 10.1 (14 days - 62 years)	9.7 ± 9.5 (14 days - 61 years)	0.981
≤ 1	49 (14.7)	42 (15.4)	
1-5	98 (29.4)	79 (29)	
6-10	63 (18.9)	44 (16.2)	0.848
11 - 20	87 (26.1)	79 (29)	
> 20	36 (10.8)	28 (10.3)	
Gender			
Male	245 (73.6)	200 (73.5)	0.871
Female	88 (26.4)	72 (26.5)	0.871
Weight (kg)	31.2 ± 23 (0.4 - 100)	32.5 ± 22.9 (0.4 - 100)	0.545
Height (meters)	1.2 ± 0.38 (0.48 - 1.88)	1.2 ± 0.4 (0.48 - 1.80)	0.770
Systolic BP (mmHg)	132 ± 18.6 (70 - 285)	135 ± 28.6 (80 - 285)	0.227
Diastolic BP (mmHg)	70 ± 17.2 (26 - 124)	70.7 ± 17.3 (26 - 124)	0.637
Antihypertensives			
0	160 (48)	128 (47.1)	
1	149 (44.7)	122 (44.9)	0.722
2	19 (5.7)	17 (6.3)	
3	5 (1.5)	5 (1.8)	
Previous surgery	13 (3.9)	11 (4)	0.870
Coa anatomy (N = 273)			
Diaphragmatic	265 (97.1)	265 (97.4)	na
Tubular	8 (2.9)	7 (2.6)	
Isthmic hypoplasia (N = 272)			
No	136 (50)	136 (50)	
Mild	107 (39.3)	107 (39.3)	na
Severe	29 (10.7)	29 (10.7)	

Abbreviations: BP = blood pressure, na = not applicable.

Table II. Procedural data.

Variable	Total group N = 333 (range or %)	Follow-up group N = 272 (range or %)	p
Balloon diameter	11.1 ± 3.7 (4 - 20)	10.45 ± 3.7 (4 - 20)	0.995
B/Ao ratio	1.17 ± 0.3 (0.61 - 3.7)	1.16 ± 0.29 (0.61 - 3.7)	0.693
No. dilations	3.6 ± 1.5 (1 - 16)	3.4 ± 1.6 (1 - 16)	0.885
Predilation gradient	50.8 ± 20.8 (10 - 160)	53.3 ± 20.9 (10 - 160)	0.144
Postdilation gradient	13.8 ± 12.2 (0 - 76)	14.5 ± 12.3 (0 - 76)	0.527
% Gradient reduction	71.5 ± 25.3 (0 - 100)	71.4 ± 24.9 (0 - 100)	0.967
Success	312 (93.7)	257 (94.5)	0.883
Procedural deaths	4 (1.2)	4 (1.5)	0.869

Abbreviations: B/Ao = balloon to aortic diameter ratio.

phies were performed in the lateral or/and left anterior oblique projections. After the aortograms and when possible, the exchange wire was positioned in the left subclavian artery. We measured the diameter of the aorta at the level of the diaphragm, the left subclavian emergence, and the transverse arch correcting the magnification factor with a known diameter catheter or a pacemaker lead. These measurements indicated the diameter of the balloon required, using the diaphragmatic aorta in most patients as a reference. With the exchange wire in place, progressively greater introducers were used to dilate the femoral artery to achieve the size required for the introduction of the balloon. We used monofoil balloons (Mansfield, Mansfield Scientific Corp., Schneider, Schneider (Europe) AG or Numed) that were advanced until the mid part of the balloon was aligned with the aortic coarctation. The balloon was inflated with increasing pressure until the waist of the balloon disappeared or the nominal burst pressure was reached. Pressure measurements and postdilation angiography were done in all cases.

Table III. Categoric all predictors of outcome, according to the univariate analysis.

Variable	No. of Patients	No. of Events	Cumulative probability of event 0*	12*	24*	36*	48*	60*	72*	84*	Relative Hazard†	(95% CI)	p**
Total	272	63	0.1328	0.1906	0.2767	0.3298	0.4555	0.4555	0.5644	0.5644			
Age													
< 1	42	22	0.2821	0.3800	0.5453	0.5453	0.8051	0.8051	0.8051		9.27	(3.49-24.59)	0.0000
1-5	79	28	0.2143	0.3078	0.4510	0.4510	0.4949	0.4949	0.6072	0.6072	4.92	(1.86-13.02)	0.0013
6-10	44	3	0.0513	0.0513	0.0513	0.1699	0.3543	0.3543			1.64	(1.44-6.12)	0.4602
11-20	79	5	0.0144	0.0347	0.0347	0.1795	0.1795	0.1795			1.00	(ref)	
> 20	28	4	0.1277	0.1923	0.1923	0.1923					3.31	(0.88-12.38)	0.0752
Anatomy													
Diaphragmatic	265	60	0.1322	0.1861	0.2765	0.3182	0.4461	0.4461	0.5569	0.5569	1.00	(ref)	
Tubular	7	3	0.1538	0.3231	0.3231	0.5938					1.75	(0.54-5.64)	0.3460
Isthmic hypoplasia													
No.	136	16	0.0593	0.0967	0.1590	0.2237	0.2754	0.2754			1.00	(ref)	
Mild to Moderate	107	30	0.1458	0.2142	0.3238	0.3802	0.4687	0.4687	0.5750	0.5750	2.37	(1.21-4.60)	0.0113
Severe	29	17	0.4074	0.5062	0.5720	0.5720	1				7.58	(3.67-15.63)	0.0000
B/Ao ratio													
< 1	53	7	0.0404	0.0647	0.0975	0.1477	0.2329	0.2329	0.7443		1.00	(ref)	
1-1.5	205	48	0.1401	0.2141	0.3301	0.3910	0.4551	0.4551	0.4551	0.4551	2.45	(1.10-5.47)	0.0284
> 1.5	14	8	0.3846	0.3846	0.3846	0.3846	1				6.32	(2.29-17.49)	0.0004
Predilation gradient (mmHg)													
< 40	59	13	0.1111	0.1111	0.2533	0.3108	0.4729	0.4729			1.00	(ref)	
40-80	186	40	0.1033	0.1883	0.2513	0.3081	0.4368	0.4368	0.5776	0.5776	1.17	(0.59-2.29)	0.6497
> 80	26	9	0.3721	0.3721	0.5116	0.5116	0.5116	0.5116	0.5116	0.5116	2.51	(1.00-6.31)	0.0500
Postdilation gradient (mmHg)													
≤ 10	132	17	0.0690	0.1186	0.1582	0.1582	0.2985	0.2985	0.2985		1.00	(ref)	
11-20	73	15	0.0615	0.0815	0.2186	0.3079	0.4463	0.4463	0.6045	0.6045	1.51	(0.74-3.06)	0.2553
> 20	66	30	0.3220	0.4431	0.5475	0.6481	0.7361	0.7361	0.7361	0.7361	4.52	(2.40-8.50)	0.0000

Abbreviations: CI = confidence intervals, B/Ao = balloon to aortic diameter ratio, ref = reference value.
* Time in months.
† The Cox Hazard ratio with the most favorable category as the reference value.
** Significance for the comparison with the most favorable category of subgroup (Log-Rank statistic).

Table IV. Forward Cox regression analysis of selected variables: multivariate analysis for proportional Hazard (dependent variable: event).

Variable	β	Wald	df	R	HR (95% CI)	p
Age	1.228	14.958	1	0.1541	3.42 (1.83-6.37)	0.0001
Anatomy	0.668	1.163	1	0.0000	1.95 (0.58-6.57)	0.2808
Isthmic hypoplasia	1.534	24.686	1	0.2039	4.64 (2.53-8.49)	0.0000
B/Ao ratio	-0.035	0.0132	1	0.0000	0.96 (0.53-1.75)	0.9085
Pre-dilation gradient	-0.089	0.1002	1	0.0000	0.92 (0.53-1.58)	0.7516
Post-dilation gradient	0.784	6.416	1	0.0900	2.19 (1.19-4.02)	0.0113

Abbreviations See other tables. β. = regression coefficient; Wald = Wald chi^2 test; df = degrees of freedom; R = standardized coefficients; HR = exponential function of β coefficients using natural log 2.74, numerically equivalent to Hazard ratio. Model significance: Overall score (6 df) = 60.35, -2LLR = 50.55, p < 0.0001.

Follow-up

Follow-up was undertaken at each institution at 3, 6 and 12 months, and every year, with clinical evaluation, echocardiography, and when indicated, with magnetic resonance imaging, CT scan or repeated catheterization. Of the total group of 333 patients, 272 (81.7%) had complete follow-up evaluation for analysis.

Statistical analysis

Analysis was made with a computer software package (SPSS 8.0 for Windows). Continuous variables are expressed as mean ± 1 SD. Comparison between two groups was conducted using the Student's t test for normally distributed continuous variables or Mann-Whitney U-test for those without normal distribution. For comparisons among three

Table V. Forward Cox regression analysis of selected variables. Multivariate analysis for proportional Hazard (dependent variable: hypertension).

Variable	β	Wald	df	R	HR (95% CI)	p
Age		26.686	4	0.1912		0.0000
≤ 1					1.00 (ref)	
1-5	0.2010	0.0939	1	0.0000	1.22 (0.34-4.42)	0.7593
5-10	-0.288	0.1419	1	0.0000	0.75 (0.17-3.36)	0.7064
11-20	0.8264	1.7597	1	0.0000	2.29 (0.67-7.75)	0.1847
> 20	1.9296	9.1910	1	0.1186	6.89 (1.98-23.97)	0.0024
Post-dilation gradient	0.4438	2.4903	1	0.0310	1.56 (0.89-2.70)	0.1146
Isthmic hypoplasia	-0.133	0.1863	1	0.0000	0.87 (0.48-1.60)	0.6660

Abbreviations: See other tables
Model significance: overall score (6 df) = 35.70, -2 LLR = 27.11, p = 0.0001

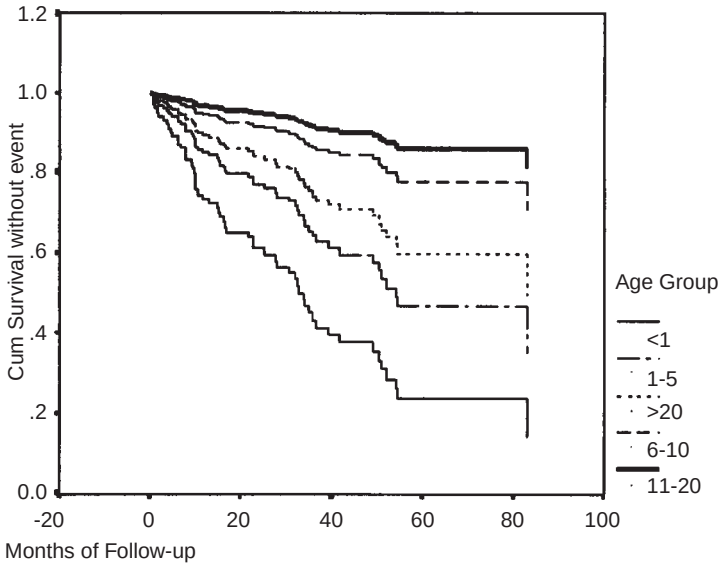

Fig. 1. Cumulative survival without event according to age group.

or more groups an ANOVA test or its equivalent nonparametric test was used. Chi square or Fisher's exact test was used for categorical variables. The association of individual variables with the clinical outcome was initially obtained by bivariate analysis. Variables were evaluated by Cox's hazard regression to identify predictors of follow-up event which included death, restenosis, aneurysm, need for redilation or surgery, or an echocardiographic gradient higher than 20 mmHg, to examine the adjusted independent effect of the relative hazards associated with factors measurable at presentation or in the immediate result, controlling for possible cofounders. Those variables were age, gender, previous surgery, associated defects, type of coarctation, degree of isthmic hypoplasia and complications. Variables that were significant as continuous variables were selected for categorical analysis, and cutoff points were determined to define subgroups for maximum comparison with log-rank statistic. For each categorical variable, Cox proportional hazard ratios were calculated, with the most favorable characteristic as the reference category. For multivariable analysis, all variables were explored in a forced model, and then the independent factors associated with reduced time to event were explored in stepwise forward Cox proportional hazard modeling. The validity of the proportionality assumption was verified graphically. Checks for possible interactions were explored.

We analyzed persistent high blood pressure as a separate event, using the same statistical approach, to determine factors related to this event.

Statistical significance was inferred at a p value < 0.05

Results

Male gender prevailed with a 73.6% of cases (245 patients) compared to female with 26.4% (88 patients). The mean age was 9.7 ± 10.1 years, mean weight was 31.2 ± 23 kg, and height was 1.2 ± 0.38 m.

Age distribution was as follows: younger than 1 year of age 49 patients (14.7%), from 1 to 5 years 98 patients (29.4%), from 6 to 10 years 63 patients (18.9%), 11 to 20 years old 87 patients (26.1%), and older than 20 years 36 patients (10.8%) *(Table I)*.

The pre-dilation systolic pressure was 132 ± 18.6 mmHg, the diastolic pressure was 70 ± 17.2 mmHg, and the mean pressure 95 ± 19.8 (range, 43-170 mmHg).

Twenty-eight patients (8.4%) presented with heart failure, in NYHA functional class III-IV.

Coarctation was diaphragmatic in 265 (97.1%) cases and tubular in 8 (2.9%). We found 136 patients (50%) without isthmic hypoplasia, 107

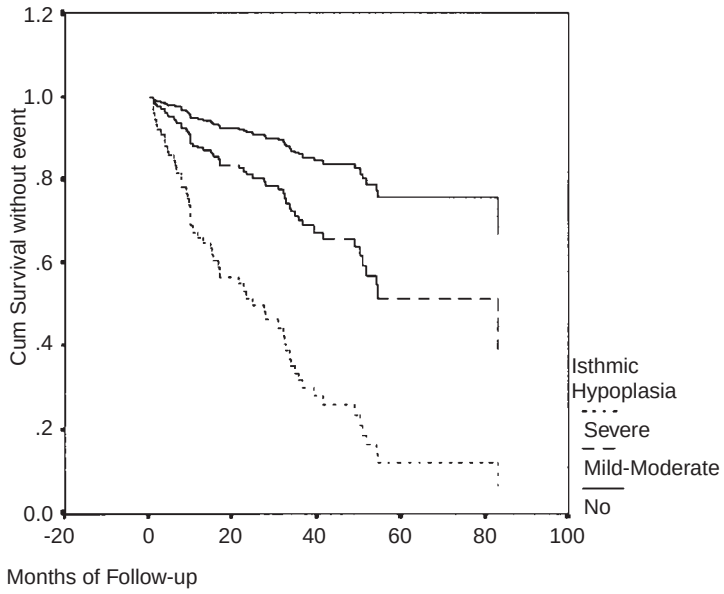

Fig. 2. Cumulative survival without event according to isthmic hipoplasia.

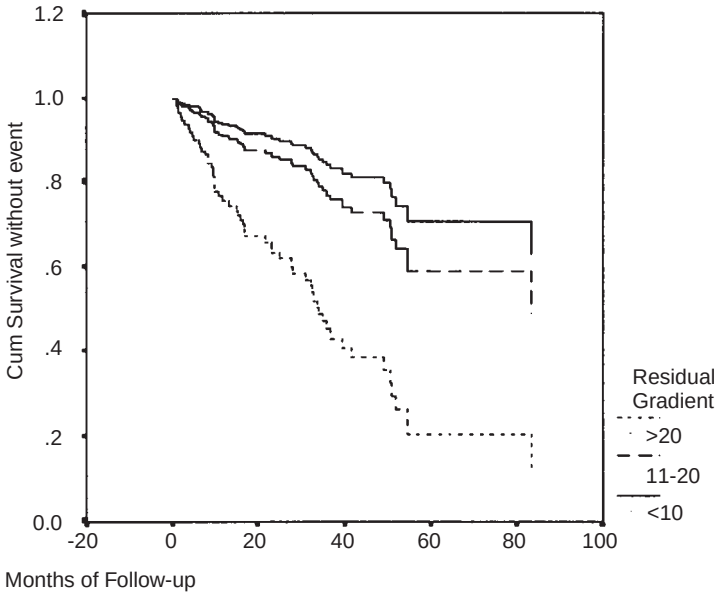

Fig. 3. Cumulative survival without event according to the residual gradient.

(39.3%) with mild-moderate hypoplasia, and 29 (10.7%) with severe hypoplasia.

Associated cardiac anomalies were found in 129 patients (38.7%). The most frequent defects were bicuspid aortic valve in 21 patients (6.3%), ventricular septal defect in 20 (6%), valvular aortic stenosis in 20 (6%), patent ductus arteriosus in 15 (4.5%), congenital mitral regurgitation in 10 (3%), and subvalvular aortic stenosis in 8 (2.4%). The remaining 25 patients (7.5%) had miscellaneous defects, some of them complex. No significant differences were found between of total group and the follow-up group.

Procedural data *Table II* summarizes procedural data. The mean balloon diameter used to dilate the coarctation was 11.1 ± 3.7 mm and the balloon to aortic diameter ratio (B/A0) was 1.17 ± 0.3. Dilation was completed with a mean of 3.6 ± 1.5 balloon inflations. The systolic gradient decreased from 50.8 ± 20.8 mmHg to 13.8 ± 12.2 mmHg after dilation ($p < 0.001$), obtaining a 71.5 ± 25.3% reduction.

Of the 333 patients, 89 (26.7%) presented complications, 6 (1.8%) were major complications, 73 (21.92%) minor, 21 (6.3%) procedural failures and 5 (1.5%) incidents. Major complications included one cerebrovascular accident, two vascular perforations and three had severe heart failure. Of these six patients with major complications, four died (procedure mortality rate 1.2%). Differences between the groups of patients that died during the procedure and survived showed that age was the major determinant for death (1.56 ± 1.72 *vs* 9.97 ± 10.12 years, $p < 0.001$).

Minor complications included vascular thrombosis of the entry site in 19 patients (5.7%), aortic aneurysm in 15 (4.5%), of which only one required immediate surgical treatment, the rest are small aneurysms that have not increased in size with time: cerebrovascular accident with complete neurological recovery in 4 (1.2%), reopening of the ductus arteriosus in 4 (1.2%), severe systemic hypertension (that required intravenous treatment) in 3 (0.9%), and 28 (8.4%) required blood transfusion. Incidents included 5 cases where the balloon ruptured without consequences.

Failure of the procedure due to technical impossibility presented in 5 cases (1.5%), and in the remaining 16 patients (4.8%) the result was considered unsuccessful. The overall success rate was 93.7% (312 patients). No significant differences in the procedural data were found between the total and the follow-up groups.

Comparative analysis between groups of procedural success and failure showed significant differences in the post-dilation systolic gradient (12.7 ± 10.5 in the success group *vs* 32.9 ± 21.2 in the failure group, $p = 0.001$), and in the complications rate (24.7% [77/312] *vs* 57.1% [12/21], $p = 0.002$). Age group (χ^2 6.82, 4df; $p = 0.146$), gender (χ^2 0.08, 1df; $p = 0.779$), previous surgery (χ^2 0.44, 1df; $p = 0.834$), associated lesions (χ^2 2.76, 1df; $p = 0.599$), anatomy of the coarctation (χ^2

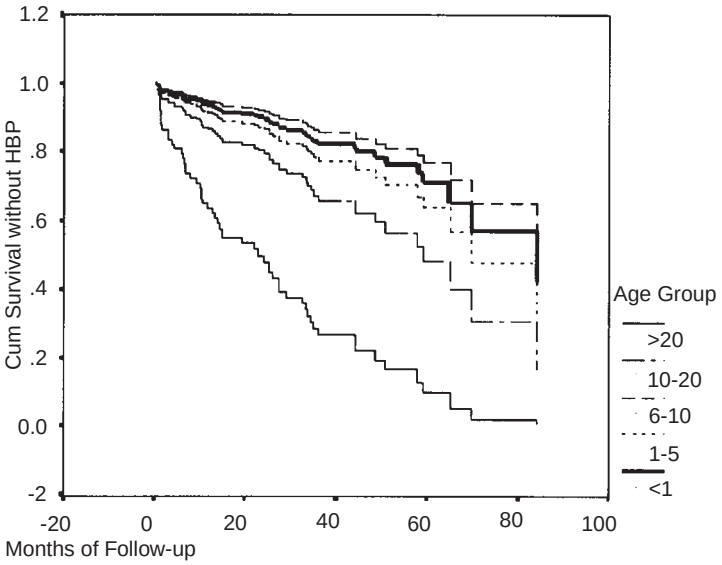

Fig. 4. Cumulative survival without hypertension according to age group.

3.10, 1df; p = 0.078), and isthmic hypoplasia (χ^2 4.08, 2df; p = 0.130) were not factors that influenced the immediate success of the procedure.

During follow-up for a mean time of 24.3 ± 20 months (range, 0-96) in 272 patients the gradient across the dilated segment determined by Doppler echocardiography (maximum gradient) was 22.15 ± 13.5 mmHg (range, 0-76).

At least one event at follow-up occurred in 63 (23.2%) patients, being restenosis the most frequent in 41 (15.1%) cases. Redilation was performed in 20 (7.4%) cases and 5 cases (1.8%) died during follow-up, three during cardiac surgery for an associated complex defect, one during surgery for restenosis after 25 months of the dilation procedure, and the other due to a CNS viral infection, 6 months after treatment. Only one case (0.4%) developed an aortic aneurysm after 6 months of follow-up submitted to surgical treatment with good result. As previously discussed, 14 patients with procedural small aneurysms have not increased in size and have not required surgery.

Sustained high blood pressure was identified in 85 (32.6%) cases.

Late outcome

The mean survival time without an event was 64.03 months (SE 3.53, 95% confidence interval [CI] 57.13-70.96). Of the 272 patients with valid follow-up data, 63 had an event at 84 months of follow-up with an estimated cumulative overall survival without event of 81% at 1 year, 72% at 2 years, 67% at 3 years, 54% at 5 years and 43% at 7 years of follow-up *(Table III)*. However, important differences were found according to the age group, presence of isthmic hypoplasia, B/Ao, and post-dilation gradient. The mean survival time without event was 37.04 (95% CI, 27.2-46.8 months) in patients ≤ 1 year of age; 57.7 (95% CI, 46.6-68.9) in patients between 1 and 5 years of age; 55.7 (95% CI, 46.9-64.6) for patients between 6 and 10 years old; 57.7 (95% CI, 53.7-61.8) in the group between 11 and 20 years-old; and 39.1 (95% CI, 32.9-45.2) in cases older than 20 years. Cases with no isthmic hypoplasia showed a mean survival time without event of 58.9 months (95% CI, 54-63.8); 62.1 (95% CI 52.3-71.8) in cases with mild-moderate hypoplasia; and 28.3 (95% CI, 19.8-36.9) in patients with severe hypoplasia. When the B/Ao was ≤ 1 (related in some way to no isthmic hypoplasia) the mean survival time was 72.4 months (95% CI, 63.9-80.9), when it was between 1 and 1.5, the mean survival time was 63.8 (95% CI, 55.9-71.7); and 34.9 (95% CI, 22.3-47.5) when the ratio was > 1.5.

A post-dilation gradient ≤ 10 mmHg was associated with a mean survival time without event of 65.4 months (95% CI, 59.5-71.4); when it was between 11 and 20 mmHg, the survival time was 66.6 (95% CI, 54.9-78.3); and 41.1 (95% CI, 28.6-56.5) with a residual gradient > 20 mmHg.

Long-term predictors of event

The probability of an event was importantly influenced by several factors. The univariate relative hazard for categorical predictors based on the Cox hazard ratio, using the most favorable category as the reference value *(Table III)*, detected that the following variables were important risk factors for long-term outcome: an age at dilation of 5 years or younger, presence of some degree of isthmic hypoplasia, a B/Ao higher than 1, and a residual gradient > 20 mmHg. Notably, this univariate analysis indicated that patients younger than one year of age were 9 times more likely to have an event than those between 11 and 20 years. Also, the presence of severe isthmic hypoplasia increased 7 times the probability of an event compared to those without it.

When a Cox regression model was performed with all mentioned variables, the significant impact on survival of the B/Ao and the pre-dilation gradient disappeared *(Table IV)*.

Long-term high blood pressure

Of the 272 cases with valid follow-up data, 209 (76.8%) had a successful dilation and no follow-up event. Systemic blood pressure in this group showed persistent hypertension in 56 (26.8%) patients. Applying the same statistical approach previously discussed, the Cox regression model showed age at dilation as the only significant variable related to follow-up hypertension, with almost a 7 fold increase in the risk when dilation was performed over 20 years of age *(Table V).*

Discussion

Several authors have demonstrated the effectiveness and safety of balloon aortic angioplasty.[12-18] However, there are still controversies regarding its use in patients younger than one year of age, the incidence of aortic aneurysms, the rate of restenosis and the ideal age to perform the procedure.

In our experience, there were significant differences between the groups of success and failure regarding the post-dilation systolic pressure gradient and in the complications rate, reflecting an inappropriate immediate result, but this result was not influenced by demographic data or anatomy of the coarctation indicating that the procedure can be performed with success in any type of patient.

Procedural and follow-up mortality was related to an average age of 1.56 years, and present only in the group of patients younger than 5 years of age (χ^2 7.08, 1df, p = 0.008). This group of patients has a higher risk of death because they commonly present in critical conditions, with heart failure or associated lesions that require additional surgical treatment.

Age was also identified as an independent risk factor for an event in the follow-up for the groups younger than 5 years of age *(Fig. 1),* where restenosis was the main concern.

Restenosis is the major problem present not only on balloon dilation, but also in surgical correction of aortic coarctation. Previous studies have shown that the groups at a greater risk to develop restenosis are neonates, especially those with isthmic hypoplasia. In our group, we found restenosis as the main event, accounting for 65% (41/63) of all events that occurred in the follow-up, and isthmic hypoplasia was an independent predictor of event, increasing the risk 2 times when it was mild to moderate, and 7 times when it was severe *(Fig. 2).*

A post-dilation residual gradient higher than 20 mmHg was also related to a poor outcome, emphasizing the need to optimize the result of the dilation procedure with the use of greater balloon diameters or the placement of a stent. We think that it is ideal to decrease the gradient below 10 mmHg, since a residual gradient between 11 and 20 mmHg increased the risk of an event 1.5 times, although it did not reach statistical significance *(Fig. 3).*

Despite a good procedural immediate result and no restenosis or increased echocardiographic gradient in the follow-up, a group of patients develop or continue with high blood pressure. We found this event in 26% (56/213) of our group and the Cox regression analysis related it only to age at dilation *(Table V, Fig. 4).* Patients dilated at an age older than 20 years had almost a 7 fold higher risk to continue or develop high blood pressure. Although, patients dilated between 11 and 20 years old had an increased risk of hypertension (HR = 2.29, 95% CI 0.67-7.75), it did not reach statistical significance (p = 0.18).

According to this results, we recommend coarctation angioplasty as an elective procedure in asymptomatic patients between 6 and 10 years old, where the rate of complications, failure of the procedure and follow-up events are the lowest. Asymptomatic patients younger than 5 years of age should be carefully followed until they are older. Symptomatic neonates and infants should be treated with angioplasty trying to obtain a residual gradient below 10 mmHg. This group of patients has the highest risk of restenosis, but they can be redilated or surgically treated when they grow up with better results. Patients older than 10 years of age should undergo dilation having in mind the risk to continue with high blood pressure despite a good immediate result. The role of stent placement in these patients remains to be determined.

Conclusions

Balloon dilation is an effective and safe alternative to treat aortic coarctation as it is reflected by a success rate of 93.7% and a major complication incidence of 1.8%, regardless of age and the anatomy of the coarctation. Only death was associated with a younger age at dilation.

Long-term outcome is better when the patient is older than 5 years of age, there is no isthmic hypoplasia and the immediate post-dilation gradient is decreased to 10 mmHg or less.

Patients younger than one year of age, with severe isthmic hypoplasia (Isthmus/Ao ratio < 0.66) and a post-dilation gradient > 20 mmHg have the highest risk to develop an event in the follow-up period, specially restenosis.

When the dilation procedure is performed in patients older than 10 years of age, and specially those older than 20 years, the probability that they remain or develop high blood pressure is increased.

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