NEW PREDICTION CRITERIA OF LONG-TERM RESULTS OF BALLOON ANGIOPLASTY IN AORTIC COARCTATION

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The aim of the investigation was to determine anatomic parameters that enable to predict a long-term outcome of transluminal balloon angioplasty of aortic coarctation.

Materials and Methods. Transluminal balloon angioplasty of aortic coarctation was performed in 51 patients, aged from 1.5 months to 35 years (mean age 6.6±6.1 years). Pressure gradient in the area of aortic isthmus stenosis varied from 31 to 103 mm Hg. The patients were followed up according to the findings of clinical examination with systemic arterial pressure measurement, echocardioscopy and multispiral computed tomography findings.

Long-term results were assessed in 32 patients (62.7%) divided into groups by the residual pressure gradient value in aortic isthmus in a long-term period after the angioplasty. Group 1 included 21 patients (65.6%) with residual pressure gradient not exceeding 20 mm Hg according to echocardiography findings; group 2 — 6 patients (18.8%) with the gradient of 21–35 mm Hg, group 3 — 5 patients (15.6%) with the gradient over 35 mm Hg.

Results. The group 2 patients in a long-term period after balloon angioplasty were statistically significantly proven to have aortic lumen sufficient for maintaining adequate hemodynamics for a long time without significant strain of adaptive forces due to the stabilization of values (plateau effect). We revealed two anatomic parameters of aortic isthmus that have effect on a long-term result of angioplasty: the coarctation length and the distance from the left subclavian artery orifice to coarctation.

Conclusion. After angioplasty the patients with the isthmus residual gradient being from 21 to 35 mm Hg in a long-term period pass into a group of patients with more favorable clinical progression of the disease. In pediatric subjects in this group the repeated correction can be delayed up to the termination of physiological growth of aorta.

For prognosis of a long-term result of transluminal balloon angioplasty there can be used such parameters as the length of the stenosis area and the distance from the left subclavian artery orifice to coarctation, the coarctation length being the most accurate parameter. The best results can be obtained if the coarctation area is less than 5 mm and the distance from the left subclavian artery orifice to coarctation is over 12 mm.

Key words: aortic coarctation; balloon angioplasty.

Aortic coarctation (ACo) is congenital segmental aortic constriction in aortic isthmus [1]. According to different authors [2–4], the pathology rate is from 6 to 14.2% of all congenital heart diseases. Now, two main treatment modalities of coarctation are known: open surgery and endovascular surgery (isolated angioplasty or combined with stenting). Transluminal balloon angioplasty (BA) is efficient and less invasive technique. It is safer than open correction of cardiac anomaly [5, 6]. At the same time there is high probability of restenosis after this procedure — 30% and more [7–9], as well as the possibility of aneurysm formation in angioplasty area [10, 11]. But even if isthmus stenosis is not eliminated completely, angioplasty can serve as a temporary correction technique that alleviates a patient's condition, and enables a child to develop. A number of researches represent anatomical assessment of thoracic aorta to improve BA results [12–15]. However, there has not been developed so far a technique for quantitative assessment of anatomical parameters enabling to predict a long-term result of BA of ACo, and the position of interventional radiological techniques in the treatment of this anomaly has not been determined yet [1, 11, 16, 17].

The aim of the investigation was to determine anatomic parameters that enable to predict a long-term outcome of transluminal balloon angioplasty of aortic coarctation.

Materials and Methods. Over the period from 2003 to 2010 in Chelyabinsk Regional Clinical Hospital transluminal BA of ACo was performed in 51 patients, aged from 1.5 months to 35 years (mean age 6.6±6.1 years). Pressure gradient in the area of aortic isthmus stenosis varied from 31 to 103 mm Hg. The patients were followed up according to the findings of clinical examination with systemic arterial pressure (AP) measurement, echocardiography (EchoCG), and multispiral computed tomography findings.

All patients underwent EchoCG on Vivid 5, Vivid 7 (General Electric, USA) apparatus. X-ray contrast investigations and endovascular surgeries were performed using angiographic unit Advantx LCV (General Electric, USA) and Infinix CF-i/SP (Toshiba, Japan). Multispiral

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computed tomography with angiographic support (MSCT-AG) was carried out on Light Speed apparatus (General Electric, USA).

Results and Discussion. Long-term results were assessed in 32 patients (62.7%). Mean follow-up period was 2.7±1.8 years. There were no lethal outcomes. The patients were divided into groups by the residual pressure gradient value in aortic isthmus in a long-term period after angioplasty. Group 1 included 21 patients (65.6%) with residual pressure gradient not exceeding 20 mm Hg according to EchoCG findings; group 2 — 6 patients (18.8%) with the gradient of 21–35 mm Hg, group 3 — 5 patients (15.6%) with the gradient over 35 mm Hg.

The groups were compared by the following parameters: AP gradient in isthmus area, systemic systolic AP (SSAP), diameter of aortic isthmus.

There was the improvement of values in Group 1. Group 2 had no significant follow-up changes according to all three parameters (Fig. 1). Therefore, we can suggest the stabilization of values — "plateau" effect. In the meantime, there was degradation of values in Group 3.

Then we performed a comparative analysis of groups according to positive and negative increment values of the indices under study using nonparametric Mann–Whitney test — the comparison of small samples under the conditions of normalcy of distribution absence. Increment was understood as the difference between the values of immediate and long-term results of angioplasty. If increment was negative, there was the decrease of the parameter, and in positive increment – there was the increase of the parameter (Tables 1, 2, 3).

Statistical comparison of mean values of positive and negative increments of the gradient in a long-term period showed:

mean values of negative increments in Group 1 to be significantly higher than in Groups 2 and 3;

mean values of negative increments in Groups 2 and 3 not to differ significantly;

mean value of positive increments in Group 3 to be significantly higher than in Groups 1 and 2;

mean values of positive increments in Groups 1 and 2 not to differ significantly.

Thus, according to statistical analysis we can suggest that Group 2 is characterized by both: low growth of gradient and low decrease of gradient, i.e. this group has gradient stabilization ("plateau" effect).

Statistical comparison of mean values of positive and negative increments of AP in a long-term period showed:

mean value of negative AP increments in groups not to differ significantly;

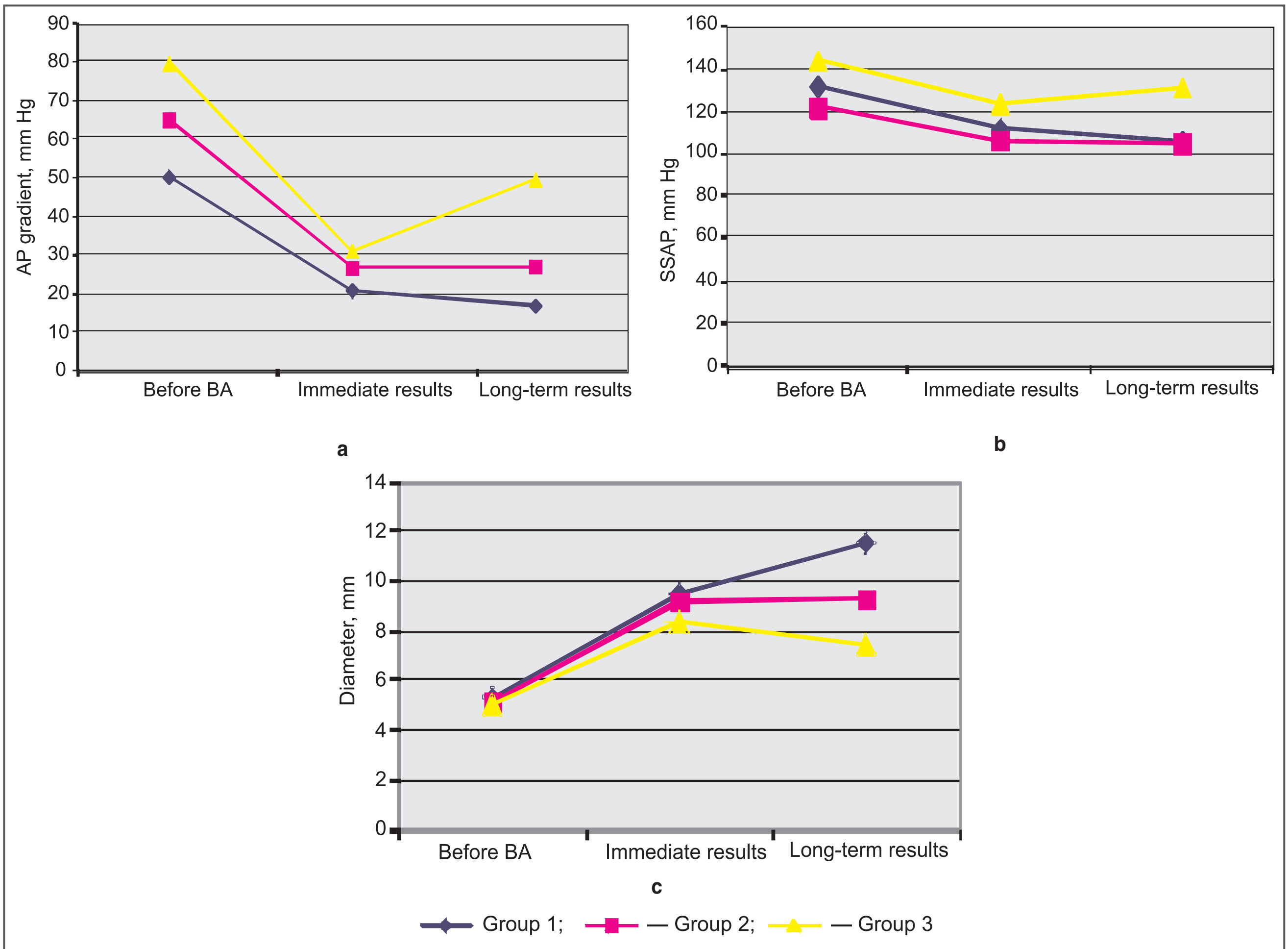

Fig. 1. Changes in mean values of parameters in groups: *a* — AP gradient; *b* — SSAP; *c* — isthmus diameter

Table 1

Mean values of positive and negative increments of a gradient

Increment sign	Mean increment value			Mann–Whitley test value	p
	Group 1	Group 2	Group 3		
Negative	15.6	4.3	3.0	U_{1-2}=0.5	p<0.05
				U_{2-3}=16	No differences
				U_{1-3}=0	p<0.01
Positive	5.1	4.5	22.8	U_{1-2}=28	No differences
				U_{2-3}=4	p<0.01
				U_{1-3} =4	p<0.01

Note: Hereinafter U_{1-2}, U_{2-3}, U_{1-3} — empirical values of Mann–Whitley test to reveal differences between the groups 1 and 2, 2 and 3, 1 and 3, respectively.

Table 2

Mean values of positive and negative SSAP increments

Increment sign	Mean increment value			Mann–Whitley test value	p
	Group 1	Group 2	Group 3		
Negative	6.0	4.5	6.3	U_{1-2}=42	No differences
				U_{2-3}=26	No differences
				U_{1-3}=15	No differences
Positive	0	5.0	14.4	U_{1-2}=3	No differences
				U_{2-3}=1.5	p<0.01
				U_{1-3}=0	p<0.01

Table 3

Mean values of positive and negative isthmus diameter increments

Increment sign	Mean increment value			Mann–Whitley test value	p
	Group 1	Group 2	Group 3		
Negative	0	1.5	2.4	U_{1-2}=0	p<0.01
				U_{2-3}=10	p<0.05
				U_{1-3}=0	p<0.01
Positive	2	1.4	0.5	U_{1-2}=28.5	No differences
				U_{2-3}=24	No differences
				U_{1-3}=10	p<0.05

mean value of positive increments in Group 3 to be significantly higher than in Groups 1 and 2;

mean values of positive increments in Groups 1 and 2 not to differ significantly.

Thus, according to statistical analysis we can suggest that Group 2 is characterized by lower AP growth than Group 3, and higher increase than Group 1.

Statistical comparison of mean values of positive and negative increments of aortic isthmus diameter in a long-term period showed:

the diameter extension in Group 1 to be significantly higher than in Group 3, while in Groups 1 and 2 the extension to be statistically insignificant;

there is a pronounced tendency for increase of mean values of negative increments of diameter in groups, i.e. in Group 1 the diameter does not decrease, in Group 2 there is moderate decrease of the diameter, and in Group 3 — the decrease is significantly higher than in Group 2, and the more so in Group 1.

It should be noted that the patients of Group 2 (in contrast to Group 3) over the whole follow-up period had no left ventricular dystrophy development according to EchoCG findings, and there was no aneurismal transformation of aorta and arterial vessels either.

The research revealed two anatomical parameters of aortic isthmus, which have an effect on a long-term result of angioplasty:

1) the length of ACo area — X1 index (Fig. 2);

2) the distance from the left subclavian artery (LSCA) orifice to coarctation — X2 index (Fig. 3).

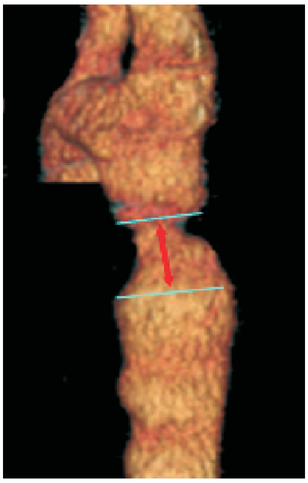

Fig. 2. The length of aortic coarctation area

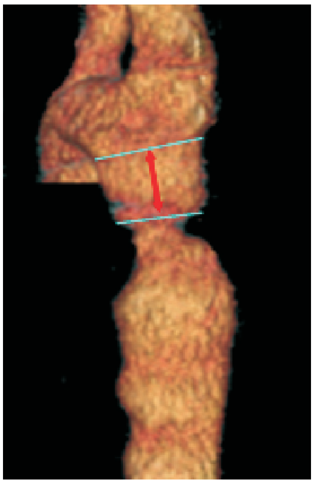

Fig. 3. The distance from the left subclavian artery orifice to coarctation

The investigation was carried out in a group of children with mean age of 7.2 years that corresponds to statistically average patient's body height of 120 cm. To take into consideration the aortic isthmus area growth dynamics in prognosis, the index should be recalculated by the correlation of a patient's body height compared to an average body height of a 7-year-old child according to the formula:

$$R1=\frac{X1\cdot 120\ cm}{\text{Patient's body height, cm}};$$

Table 4

Mean values of isthmus length (R1) and distance to LSCA (R2) in study groups

Parameter	Mean value ± m [variation interval]			Jonckheere test value, $S_{critical}(0.01)=23$	p
	Group 1	Group 2	Group 3		
ACo length, mm	3.5±1.04 [1.5; 5]	8.7±0.9 [7; 10]	16.7±0.9 [13; 22]	$S_{empirical}=27$	<0.01
Distance to LSCA, mm	16.8±3.4 [13; 23.5]	9.2±4.4 [0.5; 15]	2.0±2.0 [0; 18]	$S_{empirical}=25$	<0.01

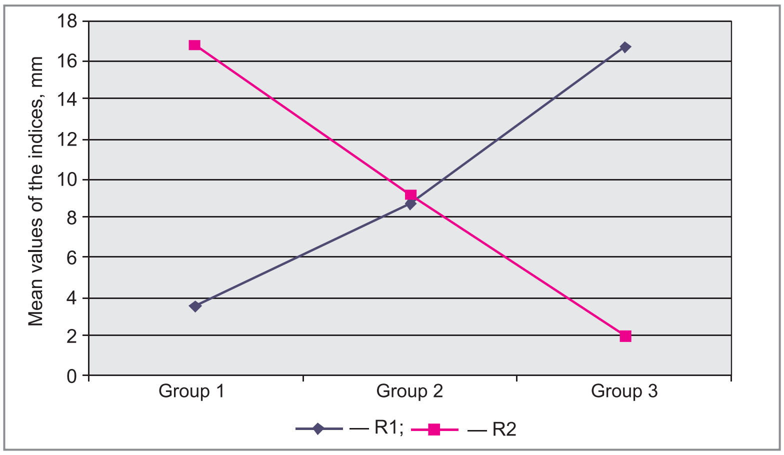

Fig. 4. Comparative analysis of mean values of R1 and R2 indices

$$R2=\frac{X2\cdot 120\ cm}{\text{Patient's body height, cm}}.$$

For comparative analysis of R1 and R2 of the study groups we used Jonckheere test that serves to reveal the tendency for changing a characteristic when passing from one sampling to another comparing three and more samplings. There was revealed significant tendency ($p<0.01$) for R1 increase when passing from Group 1 to Group 2, and then to Group 3. Thus, it is arguable that there is direct correlation relationship between the gradient value in isthmus area and R1 value: large R1 values correspond to large gradient values, and small — correspond to small.

In the same manner there was stated significant tendency ($p<0.01$) for R2 decrease when passing from Group 1 to Group 2, and then to Group 3. Therefore, it is arguable that there is inverse correlation relationship between a gradient value and R2 value: small gradient values correspond to large R2 values, and large — correspond to small (Table 4).

Note that intervals of R1 changing in groups do not overlap, i.e. R1 parameter can be a weighty identifier of the group. It means that by R1 value one can prognosticate a gradient level to a high precision. R2 parameter can also be used as an identifier of a group, though identification accuracy is slightly lower than in the first case.

Fig. 4 shows a comparative analysis of groups by mean values of R1 and R2 parameters.

The detected strong direct correlation dependence between R1 and pressure gradient in isthmus area (Y) (Spearman's rank-order correlation $r=0.9$) and strong inverse correlation dependence between R2 and Y ($r=-0.8$) enable to derive two regression equations:

$Y=9.3+2.2\cdot R1$ (determination coefficient $R=0.87$; standard error $\sigma=5.5$)

$Y=43.5-1.7\cdot R2$ (determination coefficient $R=0.68$; standard error $\sigma=9.5$)

By using these equations one can prognosticate precisely enough a gradient level (Y) both by R1 parameter (Fig. 7), and by R2 parameter (Fig. 5).

R2 parameter is rougher identifier, though according to this sampling one may reliably state that if R2 is close to zero, a patient enter Group 3.

The obtained results make it possible to define prognostic criteria to refer a patient to one of the groups:

R1 criterion:

if $R1\in[0; 5]$, a patient is referred to Group 1;

if $R1\in[6; 10]$, a patient is referred to Group 2;

if $R1>10$, a patient is referred to Group 3.

R2 criterion:

if $R2<2$, a patient is referred to Group 3;

if $R2\in[2; 12]$, a patient is referred to Group 2;

if $R2>12$, a patient is referred to Group 1.

The quality of gradient prognosis according to the above mentioned criteria was assessed

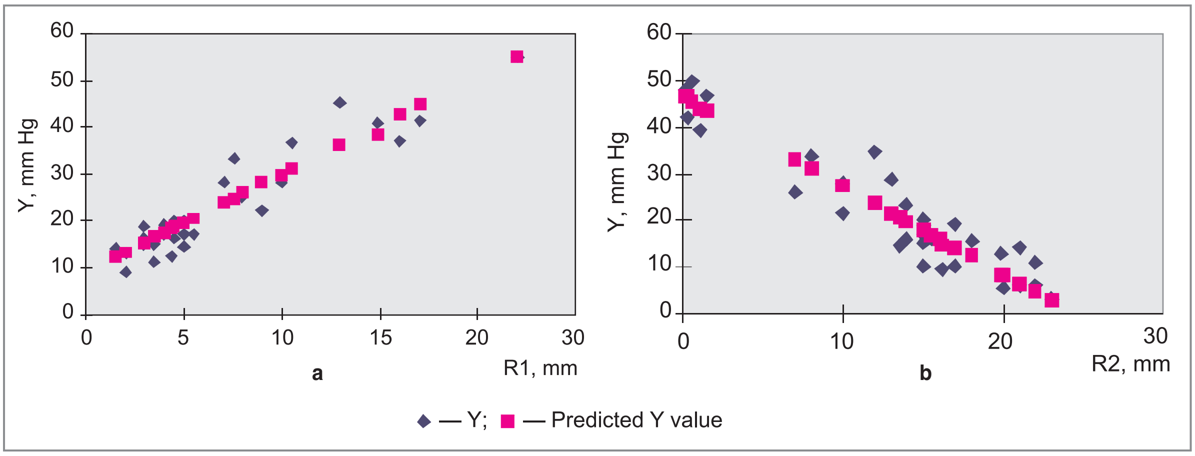

Fig. 5. Diagram of adjustment of pressure gradient value in descending aorta (Y) according to R1 (*a*) and R2 (*b*) parameter

by the following parameters: sensitivity, specificity, prognostic value and accuracy.

Following is the calculation of prognosis parameters for R2 criterion (Group 1 identification).

n11— number of patients referred to Group 1 and matched the criterion;

n12 — number of patients referred to the group, without criterion match;

n21 — number of patients, who did not enter the group, and matched the criterion;

n22 — number of patients, who did not enter the group and matched the criterion (Table 5).

1. Sensitivity (S) — probability of entering Group 1, if R2>12 (criterion match):

$$S=\frac{n11}{n11+n12}\cdot 100\%=\frac{21}{21+0}\cdot 100\%=100\%.$$

2. Specificity (Sp) – probability that a patient did not enter Group 1, if criterion did not match (R2⩽12):

$$Sp=\frac{n22}{n21+n22}\cdot 100\%=\frac{9}{2+9}\cdot 100\%=81.2\%.$$

3. Prognostic value of a positive result (P) — probability that if a criterion matches (R2>12), a patient enters Group 1:

$$P=\frac{n11}{n11+n21}\cdot 100\%=\frac{21}{21+2}\cdot 100\%=91.3\%.$$

4. Prognostic value of a negative result (N) — probability that if a criterion does not match (R2⩽12), a patient does not enter Group 1:

$$N=\frac{n22}{n12+n22}\cdot 100\%=\frac{9}{0+9}\cdot 100\%=100\%.$$

5) Accuracy of prognosis (A) — probability of error-free prognosis:

$$A=\frac{n11+n22}{n11+n12+n21+n22}\cdot 100\%=\frac{21+9}{32}\cdot 100\%=93.8\%.$$

Table 5

Calculation of prognosis parameters for R2 criterion (identification of Group 1)

Groups	R2>12	R2⩽12	Total
1	n11=21	n12=0	21
2 and 3	n21=2	n22=9	11
Total	23	9	32

Table 6

The prognosis assessment of the findings of balloon angioplasty of aortic coarctation, %

Group	Sensitivity	Specificity	Predictive value		Prediction accuracy
			positive	negative	
R1					
For Group 1	100	100	100	100	100
For Group 2	100	100	100	100	100
For Group 3	100	100	100	100	100
R2					
For Group 1	100	81.2	91.3	100	93.8
For Group 2	66.7	100	100	92.9	93.9
For Group 3	100	100	100	100	100

Table 6 shows the results of the prognosis according to two criteria.

Thus, the results of the performed investigations suggest that in patients with an isthmus residual gradient being from 21 to 35 mm Hg in a long-term period after balloon angioplasty of ACo the aortic lumen is sufficient for maintaining adequate hemodynamics for a long time without significant pressure of adaptive forces due to the stabilization of the indices ("plateau" effect). After angioplasty the patients of this group can pass into a group of patients with more favorable clinical progression of the disease. In case of a follow-up, reintervention in children can be delayed up to the age of 12–14, when the termination of physiological growth of aorta is close that improves a surgery prognosis.

Conclusion. For prognosis of a long-term result of transluminal balloon angioplasty of aortic coarctation there can be used such parameters as the length of the stenosis area and the distance from the left subclavian artery orifice to coarctation, the coarctation length being the most accurate prognostic parameter. The best results can be obtained if the coarctation area is less than 5 mm and the distance from the left subclavian artery orifice to coarctation is over 12 mm. Unacceptable results of balloon angioplasty of ACo, if stenosis is located very close to the orifice, can be related to more rigidity of aortic wall at this level.

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