Angiographic Assessment of the Stretch-Recoil-Gain Relation After Balloon Coarctation Angioplasty and Its Relation to Late Restenosis

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The effects of stretch and immediate recoil after balloon angioplasty were evaluated in 21 patients with coarctation of the aorta who underwent balloon coarctation angioplasty. A total of 28 procedures were performed in these patients, who ranged in age from 1 month to 17 years with a mean of 4.3 years. The systolic pressure gradient and coarcted diameter changed significantly from 42 ± 22 to 14 ± 9 mmHg ($P < 0.0001$) and from 4.0 ± 1.7 to 6.1 ± 2.0 mm ($P < 0.001$), respectively. Immediate recoil was responsible for the loss of 33% of the potentially achievable coarcted dimension. Recoil was determined mainly by the degree of arterial stretch. Gain increased exponentially with an increase in stretch. There was a narrow range of % stretch (60–80%) within which an effective diameter gain could be obtained. Both gain and stretch were the best predictors for late restenosis: patients with a larger immediate gain and stretch developed more restenosis. These results suggest that the stretch-recoil-gain relationship may be clinically important for evaluating the best predictor of late restenosis after balloon coarctation angioplasty.

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BALLOON angioplasty has recently become an acceptable alternative to surgery for coarctation of the aorta, especially for re-coarctation after surgery^{1–13}. The immediate result of a balloon angioplasty procedure is satisfactory both in native and operated coarctation, although there is some controversy regarding acute complications and long-term outcome in native coarctation of the aorta. Some investigations have demonstrated that aneurysm formation after balloon angioplasty occurs in 30–43% of cases with native coarctation of the aorta^{6,7}. On the other hand, the incidence of late restenosis after angioplasty is relatively high in

young infants^{1,12,13}. These 2 complications appear to be the major disadvantages of this procedure, and might result from the relation between arterial properties and the selected balloon size/pressure. There have been very few investigations of vascular properties in balloon angioplasty for congenitally stenotic lesions, although the relation between elastic recoil and late restenosis after percutaneous transluminal coronary angioplasty has previously been examined in adults with atherosclerotic lesions¹⁴. Therefore, we evaluated the relationships among arterial stretch, elastic recoil and diameter gain after angioplasty to clarify the appropriate balloon size and the relation between immediate recoil and late restenosis.

Key words:

Coarctation of the aorta
Balloon coarctation angioplasty
Elastic recoil
Arterial stretch

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$$\text{stretch} = (B - D_{\text{pre}}) / B$$

$$\text{recoil} = (B - D_{\text{post}}) / B$$

$$\text{gain} = (D_{\text{post}} - D_{\text{pre}}) / D_{\text{pre}}$$

Fig 1. Calculation of arterial recoil and stretch. B=balloon, D=diameter.

TABLE I SUMMARY OF ANGIOGRAPHIC ANALYSIS OF THE 21 PATIENTS

patient number	21 patients
age	4.3±5.5 years old
sex (male:female)	15:6
number of procedures	28 procedures
follow-up period	3.6±2.3 years (3 months to 5 years)
restenosis	5 patients (4-native, 1 postoperative)
balloon size/coarcted diameter ratio	2.5±1.2
pressure gradient (mmHg)	
before BA	42±22
after BA	14±9
diameters of coarcted site (mm)	
before BA	4.0±1.7
after BA	6.1±2.0
diameter gain (%)	67±52
elastic recoil (%)	33±13
stretch (%)	57±15

METHODS

Patients

The study population consisted of 21 patients who had undergone balloon angioplasty for coarctation of the aorta between January 1988 and January 1994. Of these patients, 14 had native coarctation of the aorta and 7 (5 with subclavian flap method and 2 with Blalock-Park anastomosis) had recoarctation after surgical repair. A total of 28 procedures were performed in these

patients: repeat balloon angioplasty was performed in 5 patients with late restenosis and 2 patients with residual stenosis at initial angioplasty. The patients ranged in age from 1 month to 17 years (mean 4.3±5.5 years) and the male/female ratio was 15/6. Associated cardiac lesions included ventricular septal defect in 11 patients, aortic stenosis and/or regurgitation in 4 and isolated form in 4. The mean follow-up period was 3.6±2.3 years (range, 3 months to 5 years). The follow-up evaluation consisted of two-dimensional echocardiography, Doppler assessment, repeat cardiac catheterization and magnetic resonance imaging. Twelve patients underwent repeat cardiac catheterization to evaluate the follow-up pressure gradient. Informed consent was obtained from the parents of the patients for the catheterization procedures, including balloon angioplasty.

Balloon Angioplasty

After conventional right and left catheterizations, the pressure gradient across the coarctation was determined and an aortogram was obtained in the anteroposterior and left anterior oblique (60°) projections. The aortic diameters were measured at a level just distal to the left subclavian artery, the narrowest site, the post-stenotic dilatation and the diaphragm with reference to the known size of a catheter. The initial balloon diameter was the same as the aortic diameter at the level of the diaphragm. Balloon angioplasty was performed using techniques similar to those described previously^{1,2,11-13}

Fig 2. (A) The relation between stretch and gain. Gain increased exponentially with increasing stretch. To obtain the appropriate gain, 60 to 80% stretch is required. (B) The positive correlation between stretch and recoil.
*closed square with repeat angioplasty.

TABLE II COMPARISON OF CLINICAL DATA IN PATIENTS WITH AND WITHOUT LATE RESTENOSIS

	restenosis (+)	restenosis (-)
number	n=5	n=14
age (years)	2.0±3.9	4.7±5.6
sex (male/female)	4:1	11:3
native:postoperative	4:1	13:1
pressure gradient (mmHg)		
before angioplasty	56±26	32±17*
after angioplasty	12±5	12±8
coarction diameter (mm)		
before angioplasty	4.6±3.2	4.2±6.6
after angioplasty	6.5±4.3	6.0±7.5
gain (%)	106±41	52±46*
stretch (%)	67±6	51±15*
recoil (%)	35±10	31±12

Two case with residual stenosis are eliminated.

*indicates $p < 0.05$.

The angioplasty catheter was positioned across the coarcted site and inflated with dilute contrast material under fluoroscopic visualization. Inflation-deflation was repeated until indentation of the balloon was eliminated. A maximal inflation pressure of 5 to 7 atm was reached in each case. If a residual systolic pressure gradient of >10 mmHg was obtained, angioplasty was repeated with a larger balloon. A postangioplasty aortogram was also performed.

Quantitative Analysis

All cineangiograms were analyzed to measure the arterial diameters. The following values were measured for each lesion, and the 3 major parameters, stretch, elastic recoil and gain, were calculated (Fig 1)^{15,16}: (1) stretch=(balloon diameter—coarcted diameter before angioplasty)/balloon diameter, (2) elastic recoil=(balloon diameter—coarcted diameter after angioplasty)/balloon diameter and (3) gain=(coarcted diameter after angioplasty—coarcted diameter before angioplasty)/coarcted diameter before angioplasty. All parameters were expressed as percentages.

Statistical Analysis

All values were presented as the mean ± standard deviation. Student's t-test and correlation coefficients were used to assess relationships between the variables. Differences at $p < 0.05$ were considered statistically significant.

RESULTS

Table I summarizes the angiographic dimensions of the coarcted sites, pressure gradient before and after angioplasty, and balloon size. The balloon size was 2.5 ± 1.2 times the coarctation size. The immediate reduction in the peak systolic pressure gradient across the coarctation was 66% (42 ± 22 to 14 ± 9 mmHg, $P < 0.0001$). The diameter of the coarcted site was significant-

Fig 3. Gain and stretch values in patients with and without late restenosis.

ly increased from 4.0 ± 1.7 to 6.1 ± 2.0 mm ($P < 0.001$).

Relations Among Recoil, Stretch and Gain

As shown in Fig 2A, there was a significant positive correlation between stretch and gain. Gain increased exponentially with increasing arterial stretch. To obtain a gain of more than 50%, more than 50% stretch must be applied. On the other hand, more than 80% stretch may increase the risk of arterial disruption because of the steep increase in gain. These results show that the most appropriate sized balloon is that which gives 50–80% stretch. There was also a significant linear correlation between stretch and recoil (Fig 2B): the greater the stretch, the larger the recoil. However, there was no significant correlation between gain and recoil. The values of stretch, recoil and gain were not statistically different between native and operated coarctations. In addition, there was no difference between these values in 2 patients with aortic wall aneurysm and those in the remaining 19 patients.

Predictors of Late Restenosis

Restenosis (defined as more than 50% pressure gradient before balloon angioplasty in the follow-up angiogram) was present in 5 patients (4 with native and 1 with operated coarctation) during follow-up. Table II

shows a comparison of the predictors in the groups with and without restenosis. Due to the small patient population, there was no statistically significant clinical factor for predicting late restenosis, including patient age. Among angiographic parameters, stretch and gain were significant predictors of late restenosis (Fig 3). Patients with a larger immediate gain after angioplasty had a tendency to develop restenosis.

DISCUSSION

Balloon angioplasty has recently become an acceptable treatment for both unoperated and operated coarctation of the aorta. However, the predictors of restenosis or aneurysm formation after angioplasty remain uncertain. These major complications may be due to the relation between arterial wall properties and balloon size/pressure. Based on the results of this study, it seems likely that the range of the optimal balloon size required to obtain an appropriate result is relatively narrow. More than 50% stretch indicates dilation to more than twice the coarcted diameter, and less than 80% stretch gives less than 5 times the coarcted diameter. Previous histologic studies of coarctation have shown that cystic medial necrosis and/or ductal tissue is present around the coarcted site. The arterial wall in this

disease might be more fragile and thus more susceptible to wall injury by balloon inflation than in pulmonary artery stenosis. Therefore, based on the relation between arterial stretch and diameter gain, one should never select a balloon that is more than 5 times the diameter of the coarcted site. To achieve a satisfactory diameter gain with a smaller immediate recoil, a balloon size giving 60–80% stretch should be chosen.

Immediate elastic recoil was dependent on arterial stretch, which was calculated by the ratio of balloon size to the diameter of the coarcted site. A similar observation was made in adults with coronary angioplasty by Rensing and colleagues^{15,16}. Elastic recoil is responsible for not only the immediate loss of luminal diameter, but also for late restenosis after balloon angioplasty. However, the mechanism of elastic recoil in coarctation of the aorta may be different from that in adults with coronary artery disease. In adults, the mechanism is attributed to spasm or nonocclusive mural thrombus^{15,16}. In coarctation of the aorta, on the other hand, it is caused mainly by arterial elasticity, which may not be responsible for late restenosis. These facts suggest that the concept of elastic recoil in studies of adults with coronary disease may be inapplicable to congenital heart disease. Therefore, further investigation of the stretch-recoil-gain relationship is required in balloon angioplasty for other congenital stenotic lesions.

Similarly, the histologic mechanism of late restenosis is clearly different from that of immediate recoil in coarctation of the aorta. Immediate recoil may result mainly from the elastic properties of the arterial wall, which is not injured by the inflated balloon. On the other hand, late restenosis may be due to excessive intimal hyperplasia following intimal-medial damage^{17–20}. In this study, patients with a larger gain developed late restenosis. Although we can not clearly explain the cause of this finding, deep arterial tearing due to overdilation may induce more excessive cellular proliferation than superficial tearing, since overdilation induces platelet activation and the release of various growth factors for smooth muscle cells such as transforming growth factor and platelet-derived growth factor^{17,18}.

In summary, the present study indicates

that elastic recoil immediately after balloon angioplasty in coarctation of the aorta is responsible for residual stenosis after the angioplasty procedure. Both diameter gain and elastic recoil are determined by the extent to which the artery is stretched. To obtain an appropriate diameter gain at the coarcted site, arterial stretching of 60–80% is required. Moreover, gain and stretch may be the best predictors of late restenosis: patients with a larger gain and stretch have a tendency to develop late restenosis. Thus, the stretch-recoil-gain relationship may be clinically important for evaluating the best predictor of late restenosis after balloon coarctation angioplasty.

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