intravascular stent implantation has become the preferred treatment for the pre- and postoperative peripheral (P) pulmonary artery stenosis (PS) that complicates complex heart anomalies, but there are concerns regarding size mismatch following somatic growth and of the long term safety of implanted metallic stents, particularly in young children. Consequently, although its success rate is less than that achieved with stents, percutaneous transluminal balloon angioplasty (PTA) remains an option for some pediatric cases of PPS.

We have observed that some stenotic pulmonary artery (PA) lesions show satisfactory late growth after PTA despite an initial poor response and the purpose of this study was to determine (1) how often such growth of the stenotic PA (ie, remodeling) occurs and (2) what factors influence remodeling and what is their mode of action.

Methods

Study Patients

We evaluated the pulmonary angiograms of 17 peripheral PS lesions before and after PTA in 14 patients in whom PTA had been performed between March 1993 and September 1999 and which had been judged successful. The median age at PTA and the interval from PTA to follow-up angiography was 21 months (range: 4 months to 9 years 7 months) and 11 months (range: 2–18 months), respectively.

The cardiac anomalies of the patients are shown in Table 1. The PS lesions were characterized (1) native PS not related to surgical plasty and (2) surgical PS related to the distal site of an outflow patch, a conduit or a nonfunctioning systemic–pulmonary shunt.

PTA

A standard PTA technique was used. We usually selected a high-pressure balloon catheter with a nominal pressure of 10 atmospheres and a balloon diameter of approximately 3–4-fold that of the stenosis.

Cineangiographic Analysis

Cineangiography was performed using 1–2 ml/kg of nonionic contrast media, and views from different angles were used to delineate the entire lesion. The diameter of a stenotic lesion was measured on the pulmonary angiogram before, immediately after, and at late follow-up after PTA. Measurements were corrected for magnification using an appropriately positioned grid. The predicted percent of normal of the diameter (%N) was calculated as: (the actual diameter of the stenosis / predicted diameter in normal subjects) × 100. The predicted diameter is calculated from the patient’s body surface area using original data generated from patients with Kawasaki Disease (unpublished data).

Remodeling was defined as an increase of more than 30% in the %N of the peripheral PA diameter at late follow-up compared with the diameter immediately after PTA. Remodeling occurred in 6 of 17 lesions (35%), and the pressure gradient immediately after PTA was significantly smaller (<10mmHg) in the (+) group than in the (−) group. Late expansion of the lesion (remodeling) occurs after PTA in some children with PPS and an adequate initial reduction in the pressure gradient favors subsequent remodeling.

Key Words: Percutaneous transluminal balloon angioplasty; Peripheral pulmonary artery stenosis; Remodeling
The following factors were compared between the 2 groups: age at PTA, time from the first surgical procedure to PTA, type of stenosis, ∆D, and the acute change in the pressure gradient across the lesion following PTA.
Statistical Analysis

Results are expressed as mean ± standard deviation (SD). Statistical analysis was done by 2-tailed Student's t-test or Fisher’s exact probability test using StatView 4.5 software (Abacus Concepts, Berkeley, CA, USA). A p value less than 0.05 was taken as statistically significant.

The method of mean percent difference, which is derived from the absolute difference between 2 observers divided by the average of the readings, was used to analyze inter-observer variability in the measurement of the PA diameter and the predicted %N.

Results

Remodeling

We detected remodeling in 6 of 17 lesions (35%): the mean values of the % increase in the predicted %N in the (+) group and the (–) group were 79±49% and 6±19%, respectively (p<0.05).

Comparison of the Remodeling (+) and (–) Groups

Clinical Background There was no significant difference between the 2 groups in age at PTA or in time from the first surgical procedure to PTA. There were more type (2) lesions (4 of 6) in the (+) group than in the (–) group (3 of 11), but the difference was not statistically significant (p=0.11) (Table 1).

Immediately After PTA The actual diameter, the predictive %N and ΔD of the stenosis immediately after PTA were slightly smaller in the (+) group than in the (–) group although the differences were not statistically significant. The pressure gradient immediately after PTA was significantly smaller in the remodeling (+) group than in the (–) group (Table 2, p<0.05). The pressure gradient became less than 10mmHg immediately after PTA in 4 of 6 (66.7%) lesions in the remodeling (+) group, but remained greater than 10mmHg in all lesions of the (–) group (Fig 1, p<0.05).

Late Follow-up The actual diameter and the predictive %N of the lesion at late follow-up tended to be larger in the remodeling (+) group than in the (–) group, although not statistically significant (p=0.271 and 0.299, respectively). Furthermore, 5 of 6 (83%) lesions became larger than 70% of the %N in the remodeling (+) group, compared with 6 of 11 (55%) in the (–) group (Table 2, p=0.333).

Inter-Observer Variability in the Measurement of PA Diameter and the Predicted %N

The inter-observer variability of the cineangiographic measurement of the PA diameter and the predicted %N in this study (17 measurements in 7 patients) was 9.8±6.6% and 9.9±6.0%, respectively.

Discussion

Vascular remodeling occurs after coronary artery interventions11–14 and after balloon dilatation of coarctation of the aorta.15–18 Although there has been extensive work on the acute and follow-up results of balloon dilatation for peripheral pulmonary stenosis there is little information on remodeling.

In this study, we confirmed that although adequate dilatation could not always be achieved immediately after PTA, some lesions were remodeled and the diameter improved more than 70% of normal during follow-up. Only a few of our patients routinely undergo follow-up angiography after PTA because we perform surgery or stent implantation when balloon dilatation is judged to be ineffective, so the patients in this study might have attained a relatively good acute outcome of PTA, and if all patients, including the patients in whom PTA was unsuccessful, were considered, the incidence of remodeling may be less than observed in this study. However, we believe that the growth of the PA

![Fig 1. Relationship between pressure gradient immediately after PTA and % increase of the predictive %N at late follow-up. In the remodeling (+) group (open circles), the pressure gradient was less than 10mmHg immediately after PTA in 4 of 6 (66.7%) lesions, but it exceeded 10mmHg in all lesions of the (–) group (closed circles). PG, pressure gradient immediately after PTA; ΔN%, % increase of the predictive %N at late follow-up.](image1)

![Fig 2. Pulmonary angiograms before (A), immediately after (B), and at late follow-up (C) of a 26-month-old patient with tetralogy of Fallot repaired with a right ventricular outflow patch. The predictive %N of the right pulmonary artery stenosis before and immediately after PTA was 34% and 46%, respectively. The pressure gradient across the stenosis fell from 33mmHg to 3mmHg immediately after PTA. The predictive %N at late follow-up was 70% and the % increase of the predictive %N was 53%. We defined such an increase in the predictive %N of the diameter at late follow-up as remodeling.](image2)
from 46±16% of the predictive diameter to 78±15% in the remodeling (+) group would be beneficial, particularly for infants who are not candidates for stent implantation.

Several factors may determine the occurrence of remodeling. Rao et al reported that the pressure gradient after PTA determined remodeling of the lesion in coarctation of the aorta16 and in the present study, a post-PTA pressure gradient less than 10 mmHg was the only predictor of remodeling. Although we could not establish an association with a change in blood flow volume, increased blood flow might be a further factor promoting remodeling, whereas age or the characteristics of the lesion seem to be less important. If the pressure gradient is less than 10 mmHg immediately after PTA, we may not rush to further intervention, even though the immediate morphological change might be unsatisfactory.

In this study, none of the patients had progressive stenosis in the contralateral PA, but this may contribute to remodeling following PTA in patients with bilateral pulmonary stenosis.

The type of stenosis may be another factor that determines late remodeling. As shown in Table 1, the number of type (2) stenoses was greater in the remodeling (+) group than in the (−) group, which suggests that type (2) stenosis is more likely to undergo remodelling, although the difference did not reach statistical significance.

Changes in blood flow volume and the vascular resistance at the peripheral PA distal to the stenosis are also considered to be the factors that might influence remodeling, but we could not compare these factors because of incomplete data.

In this study, inter-observer variability in the measurement of PA diameter and the predicted %N was considered to be slight.

Study Limitation

As histopathological examination was impossible in this study, the structural features of remodeling at the site of stenosis were not examined.

We conclude that late growth of the lesion (remodeling) occurs after PTA in some patients with PPS and that an adequate reduction in the pressure gradient may promote remodeling.

Acknowledgment

We thank Dr Peter M. Olley, Professor of Pediatrics, University of Alberta, for his language consultation.

References