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Assessment of adequacy of pulmonary arterial banding by phonocardiogram[1]

Kalim-Ud-Din Aziz, Zoltan G. Mesko, and R. Curtis Ellison

From the Department of Cardiology, Children's Hospital Medical Center, and the Department of Pediatrics, Harvard Medical School, Boston, Massachusetts, U.S.A.

The phonocardiograms of 17 patients with ventricular septal defect and pulmonary arterial band were analysed in order to assess their use in evaluating the adequacy of pulmonary arterial banding. In patients in whom the second heart sound was widely split (greater than 45 msec) the pulmonary arterial constriction was found to be adequate, with low pressure in the pulmonary artery distal to the band. The pulmonary component of the second sound was usually diminished.

If, on the other hand, the second heart sound was narrowly split (less than 40 msec) with an increased pulmonary component, either the band was inadequate with persistent pulmonary arterial hypertension, or the band satisfactorily constricted the main pulmonary artery but was located at a distal position (greater than 2·1 cm) from the pulmonary valve. In both of these situations, the pulmonary valve closing pressure was found to be increased giving rise to the narrowly split second sound.

Pulmonary arterial banding is an effective palliative procedure in the treatment of children with ventricular septal defect, large left-to-right shunt, and pulmonary arterial hypertension. An appropriate constriction of the main pulmonary artery will result in reducing the pulmonary blood flow and pulmonary arterial pressure and probably will prevent progression of pulmonary vascular disease. The adequacy of the constriction may be assessed in terms of clinical improvement and by cardiac catheterization. The present study was undertaken to explore the usefulness of the phonocardiogram in evaluating the adequacy of the pulmonary artery banding.

Material and methods

Seventeen patients who had pulmonary arterial banding for ventricular septal defect were studied by cardiac catheterization 1 to 10 years (mean 5·5 years) after pulmonary arterial constriction. In all but one patient, cardiac catheterization had also been performed before the pulmonary arterial banding. The age of the patients at the time of the postoperative catheterization varied between 1·1 and 10·9 years, with a mean of 5·9 years. The systolic pressure in the pulmonary arteries distal to the band was used to determine the adequacy of the banding. If the systolic pressure in the pulmonary artery distal to the band exceeded 50 mmHg, the patients were classified as having inadequate bands; if the distal pressure was less than 50 mmHg, the patients were classified as having adequate bands.

In addition to the pressure in the distal pulmonary artery, other measurements obtained at cardiac catheterization included the right ventricular pressure and the gradient across the band. Also, the pulmonary valve closing pressure (i.e. the diastolic pressure at the time of the dicrotic notch) and the mean diastolic gradient across the pulmonary valve were measured.

The position of the band was determined from angiograms in the lateral projection by measuring the distance of the band from the pulmonary valve cusps during ventricular diastole (Fig. 1). The measurements were corrected for x-ray magnification. As illustrated in Fig. 1, the area between the pulmonary valve cusps and the pulmonary arterial band is referred to as the pulmonary arterial chamber, and the part of the pulmonary artery distal to the band is referred to as the distal pulmonary artery.

External phonocardiograms were recorded at the time of the follow-up cardiac catheterization. Tracings were obtained in the standard areas with the patients resting quietly in the supine position; no sedation was given. The pulmonary component of the second sound recorded at the second left intercostal space was analysed for intensity and timing, as related to the aortic component of the second sound. The intervals between the first heart sound and the peak of the systolic murmur and between the first heart sound and the pulmonary

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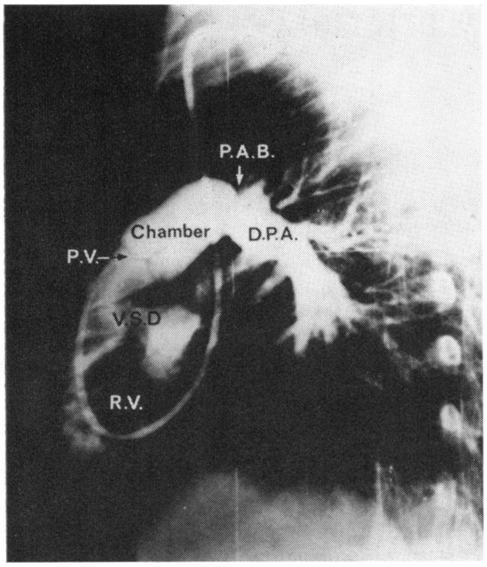


FIG. 1 *Position of pulmonary artery band as shown by angiography. The lateral view of the right ventricular angiogram obtained in Case 12 (Table 1). RV, right ventricle; VSD, ventricular septal defect; PV, pulmonary valve; PAB, pulmonary artery band; DPA, distal pulmonary artery.*

component of the second heart sound were also measured. The respiratory phases were recorded by a thermistor secured to the nares. A Cambridge MCIV multichannel photographic recorder was used, and the recordings were obtained at low (200 cycles/second), medium (400 cycles/second), and high (800 cycles/second) frequencies using high pass filters.

Results

The detailed data are given in Table 1 and summarized in Table 2. The patients were divided into two groups depending on the adequacy of the banding. Group I refers to patients with adequate bands (distal pulmonary arterial systolic pressure less than 50 mmHg) and group 2 refers to patients in whom the bands were deemed inadequate.

There were 15 patients in group 1 with adequate banding as judged by systolic pressure in the distal pulmonary artery between 8 and 48 mmHg. The right ventricular systolic pressure ranged from 54 to 140 mmHg, with a mean of 96 mmHg, and the gradient across the band varied between 17 and 131 mmHg, with a mean of 70 mmHg.

Group 1 was further divided into 1A and 1B according to the degree of splitting of the second heart sound as shown in Table 2. The A2-P2 interval in the 11 patients in group 1A exceeded 45 msec (range 45 to 80 msec). The A2-P2 interval during respiration was fixed in 7 of the patients and varied by 10 msec or less in the remaining 4. Intensity of the pulmonary second sound at the second left intercostal space was less than that of A2 in 10. The distance between the pulmonary valve and the band varied between 0·9 and 2·1 cm (mean 1·4 cm) in the 10 patients of this group in whom it could be measured. The mean diastolic gradient across the pulmonary valve in group 1A varied from 5·5 to 11·9 mmHg (mean 9·0 mmHg).

In the 4 patients making up group 1B, the A2-P2 interval was 40 msec or less (range 20–40 msec); slight respiratory variation was noted in 3. The intensity of the pulmonary component of the second sound was increased in all. The pulmonary valve to band distance was considerably greater in this group of patients than 1A, ranging from 2·4 to 2·9 cm (mean 2·7 cm) in the 3 in whom it could be measured. The mean diastolic gradient across the pulmonary valve was increased in comparison to group 1A, being 19·9 to 26·4 mmHg, with a mean of 22·2 mmHg.

Thus, in these adequately banded patients, the degree of splitting of A2-P2, and to a lesser extent the intensity of the pulmonary component of the second sound, was related to the distance of the band from the pulmonary valve; the shorter the valve-band distance, the more delayed was the valve closure sound (see Fig. 2). The A2-P2 interval was also re-

FIG. 2 *Relation between A2P2 interval and valve to band distance in the adequately banded patients. Note the greater the A2P2 interval, the shorter the valve to band distance.*

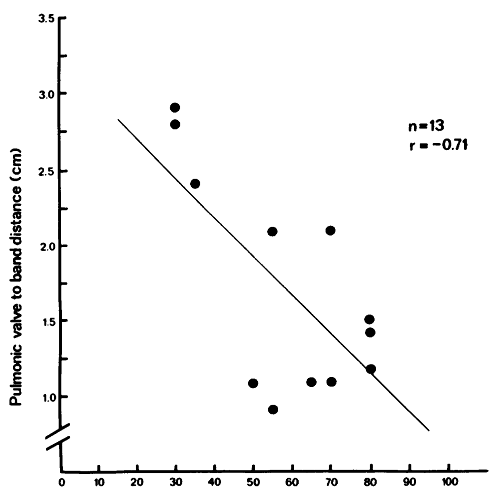


TABLE 1 *Data on patients with ventricular septal defect and pulmonary arterial band*

Group	Case No.	Distal pulmonary arterial pressure (mmHg)	Right ventricular pressure (mmHg)	Gradient across band (mmHg)	Pulmonary valve closing pressure (mmHg)	Mean diastolic gradient across PV (mmHg)	Pulmonary valve band distance (cm)	A2-P2 interval (msec)	Intensity of P2
Patients with adequate bands									
IA	1	21/8	85/6	64	—	—	1·2	80	Decreased
	2	26/4	54/6	28	24	9·8	1·1	60–70	Decreased
	3	18/12	68/10	50	19	5·5	1·2	80	Decreased
	4	20/7	100/7	80	15	6·3	1·4	80	Decreased
	5	19/7	140/12	131	—	—	2·1	70	Decreased
	6	23/11	102/5	79	26	9·8	2·1	55	Decreased
	7	28/15	114/10	85	18	—	1·1	45–50	Decreased
	8	29/12	110/8	65	—	—	—	50	Decreased
	9	14/6	105/7	90	17	11·0	1·5	80	Decreased
	10	31/5	98/6	67	18	9·3	1·1	70–80	Decreased
	11	48/20	65/7	17	24	11·9	0·9	50–60	Increased
Mean values		25/9	95/8	69	20	9·0	1·4	65	
IB	12	30/15	115/5	84	39	19·9	2·4	30–40	Increased
	13	8/4	113/11	105	38	26·4	2·8	20–35	Increased
	14	28/12	86/10	61	36	21·8	2·9	25–30	Increased
	15	40/15	70/10	30	38	20·5	—	40	Increased
Mean values		26/11	96/6	70	38	22·2	2·7	29	
Patients with inadequate bands									
II	16	64/40	90/6	18	50	36·4	—	25–30	Increased
	17	59/27	102/5	41	45	52·3	1·6	20	Increased
Mean values		62/33	96/5	29	48	44·4	1·6	23	

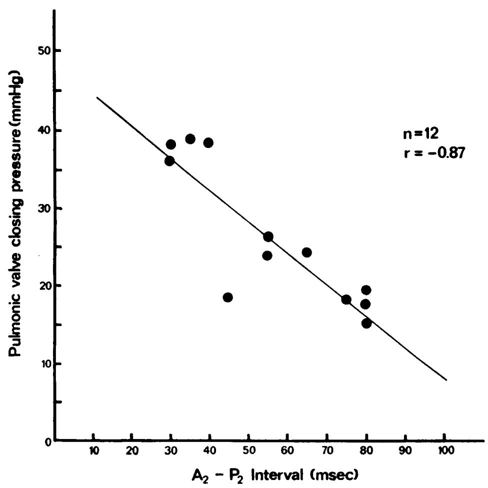
A2, aortic second sound; P2, pulmonary second sound.

lated to the diastolic pressure in the pulmonary arterial chamber at the time of the pulmonary valve closure in the 12 patients in whom chamber pressures were obtained (Fig. 3). An earlier closure of the pulmonary valve corresponds with a higher pressure, and vice versa. These two correlates of the A2-P2 split (the pulmonary valve-band distance and the diastolic pressure in the pulmonary arterial chamber) also related closely to each other (Fig. 4). It was found that the more distal the band from the pulmonary valve, the

TABLE 2 *Phonocardiographic findings in patients with pulmonary arterial bands*

Group	No. of patients	Intensity of P2 (relative to A2)	A2-P2 interval
I (adequate bands)			
A	11	↓ (10 of 11)	>45 msec
B	4	↑	<40 msec
II (inadequate bands)	2	↑	<40 msec

FIG. 3 *Relation between the A2P2 interval and the pulmonary valve closing pressure in the adequately banded patients. An increasing A2P2 interval is associated with a decreasing diastolic pressure at the time of pulmonary valve closure.*



higher was the diastolic pressure in the pulmonary chamber at the time of valve closure.

The 2 patients in group 2 were deemed to have an inadequate band as judged by raised systolic pressure (exceeding 50 mmHg) in the pulmonary artery distal to the band. The pulmonary arterial systolic pressures were 59 and 64 mmHg, respectively (mean 62 mmHg), in these 2 patients and the systolic gradients across the band were 18 and 41 mmHg (mean 29 mmHg). The diastolic pressures in the pulmonary arterial chamber at the time of valve closure were 45 and 50 mmHg (mean 48 mmHg) and the mean diastolic gradients across the pulmonary valve were 36 and 52 mmHg (mean 44·4 mmHg). The pulmonary valve to band distance in the one patient in whom it could be measured was 1·6 cm. Both patients had narrow splitting of A2-P2 (20–30 msec) with an increased intensity of the pulmonary second sound (Fig. 5).

It should be pointed out that groups 1A and 1B are essentially identical as far as distal pulmonary artery pressure, right ventricular pressure, and gradient across the band are concerned, indicating adequacy of the pulmonary arterial constriction. As shown in Table 1, the main characteristics of group IB are the closing pressure of the pulmonary valve and the mean diastolic gradient across the valve, which are considerably increased over group 1A. These are reflected in the shorter A2-P2 interval and increased P2, and seem to be related to the much greater pulmonary valve-band distance, giving a larger chamber between valve and band.

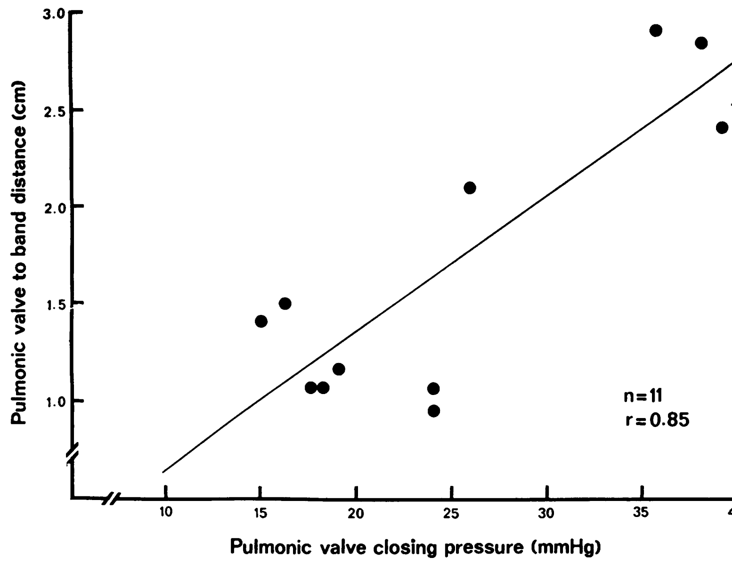


FIG. 4 *Relation between the pulmonary valve closing pressure and the valve – band distance in the adequately banded patients. Note that a distal position of the band was associated with a higher diastolic pressure at the time of pulmonary valve closure.*

The inadequately banded patients showed a similar right ventricular pressure but a significantly higher pressure distal to the band. The persisting pulmonary hypertension is reflected in the high pulmonary valve closing pressure and the high diastolic gradient across the pulmonary valve. These factors cause an earlier and more forceful closure of the pulmonary valve cusps in inadequately banded patients.

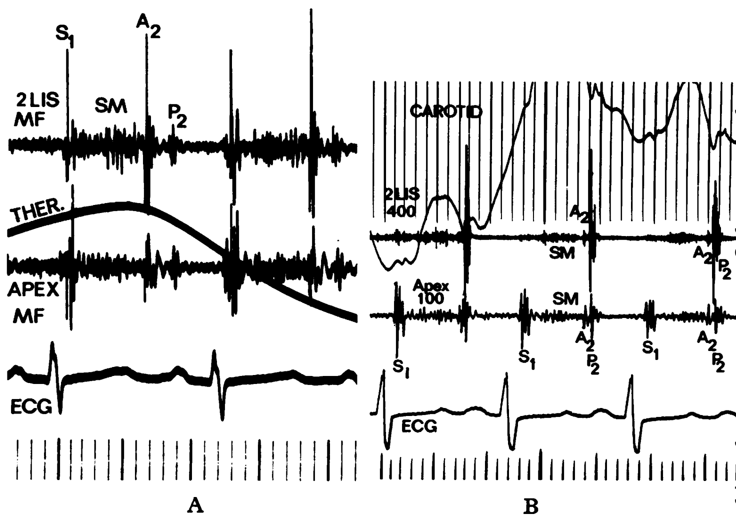


FIG. 5 *A. The phonocardiogram from a patient with ventricular septal defect and an adequate and proximally located pulmonary arterial band (Case 3, Table 1). The distal pulmonary arterial pressure was 18/12 mmHg. The tracing shows a widely split (80 msec) second sound with a diminished P2. B. The phonocardiogram of a patient with ventricular septal defect and an inadequately banded pulmonary artery (Case 16, Table 1). The distal pulmonary arterial pressure was 64/40 mmHg. The tracing shows a narrowly split (25 msec) second sound with a conspicuously increased pulmonary component. 2LIS, second left intercostal space; MF, medium frequency; THER, thermistor; S1, first heart sound; A2, aortic component of second heart sound; P2, pulmonary component of second heart sound; SM, systolic murmur.*

The S1 to peak of the systolic murmur interval and the S1 to P2 interval were measured in all patients, but no correlation with the haemodynamic state was noted.

Discussion

Takahashi *et al.* (1968) reported the comparative pre- and postbanding auscultatory findings in patients with ventricular septal defect. In loosely banded patients, the P2 remained loud in the majority and a more noticeable split was noted in only 4 out of 14; in tightly banded patients the P2 intensity was reduced in 6 out of 8 patients, and in 4 out of 8 a more noticeable splitting was noted.

Among the phonocardiographic parameters evaluated in the present study, only the timing of the pulmonary second sound, and in some cases its intensity, were found to be related to the adequacy of the banding. In the 2 patients in whom the band was inadequate, the pulmonary second sound was accentuated and closely split. The high pulmonary valve closing pressure, the high mean diastolic gradient across the pulmonary valve, and the pulmonary arterial hypertension shown at catheterization explain the closely split second sound with increased P2 that was observed in the inadequately banded patients.

In adequately banded patients there were two groups: in one (1A), a wide split was noted and the intensity of P2 was reduced in all but one patient. The decreased and delayed pulmonary second sound in these patients seems to relate to the proximal position of the band, with only a small chamber between the pulmonary valve and the band. It is suggested that the elastic recoil of this proximal chamber is small; consequently the diastolic pressure at the time of pulmonary valve closure and the diastolic gradient across the pulmonary valve are low, and hence a delayed and decreased intensity sound results.

In 4 patients in group 1B, a closely split S2 with a loud pulmonary component was noted in spite of an adequate band. The pulmonary valve-band distance in the 3 patients where this could be measured was found to be significantly greater than in group 1A. It is suggested that there was sufficient elastic recoil from this larger chamber between pulmonary valve and band to produce a higher diastolic pressure and higher diastolic gradient across the pulmonary valve, causing earlier and louder closure of the pulmonary valve.

Therefore, when the second heart sound is found to be widely split (greater than 45 msec) with a low intensity component, one may be assured that the pulmonary artery banding is adequate and the band is proximally located. On the other hand, if S2 is narrowly split and P2 is of increased intensity, two explanations are possible. Either, there is an inadequate band, with persistence of pulmonary artery hypertension, or there is an adequate band located at a distal position (over 2·1 cm) from the pulmonary valve. In this situation, distinction between adequate and inadequate banding is not possible by means of phonocardiography, and cardiac catheterization is necessary for assessment of the haemodynamic state.

Reference

Takahashi, M., Lurie, P. R., Petry, E. L., and King, H. (1968). Clinical and hemodynamic effects of pulmonary artery banding. *American Journal of Cardiology*, **21**, 174.

Requests for reprints to Dr. R. C. Ellison, Department of Cardiology, The Children's Hospital Medical Center, 300 Longwood Avenue, Boston, Massachusetts, 02115, U.S.A.