Two-dimensional Echocardiographic and Color Flow Doppler Evaluation of Ductal Occlusion With the Rashkind Prosthesis

Norman N. Musewe, MD, Lee N. Benson, MD, Jeffrey F. Smallhorn, MBBS, and Robert M. Freedom, MD

To evaluate the results of ductal occlusion with the Rashkind prosthesis, 78 children (group 1, 19 boys and 59 girls; mean age at occlusion, 4.5±4.0 years) with isolated patent ductus arteriosus (n=73) or in association with other lesions (n=5) were evaluated by pulsed and color flow Doppler 9±7 months (range, 2–26 months) after occlusion. Thirty children who had undergone patent ductus arteriosus ligation (group 2, 9 boys and 21 girls; mean age at study, 5.7±4.9 years; mean follow-up after ligation, 44±58 months) were evaluated in the same way. The prevalence of residual ductal shunting and the main pulmonary arterial flow patterns were recorded. Residual ductal shunting in group 1 was 38% on day 1, decreasing slowly to 31% at 3 months, 27% at 6 months, and 19.7% at 1 year or more due to further spontaneous shunt resolution. The residual shunting rate in group 2 (6%) was significantly lower than that at 1 year or more in group 1 (p<0.001). Successful reocclusion in 5 of 6 in a subset of patients in group 1 followed for 1 year or less reduced further the prevalence of residual shunting. Residual shunting after patent ductus arteriosus occlusion is more common than after ligation, but continues to decrease during follow-up. (Circulation 1989;80:1706–1710)

Percutaneous closure of the persistently patent ductus arteriosus (PDA) with the Rashkind prosthesis has been reported to be effective in eliminating ductal shunting with low morbidity and no mortality.1,2 Although, to date, use of the Rashkind occluder device has been limited to a few centers, it may soon gain wide acceptance as the method of choice for ductal closure in appropriately selected cases. The reported experience with this device3,4 suggests complete ductal occlusion in 60–80% of patients. Although attention has naturally focused on elimination of ductal shunting, criteria for complete ductal occlusion have, so far, been based either on auscultatory findings alone or in combination with pulsed Doppler interrogation of the main pulmonary artery after device placement.1,2,4 The time course of shunt disappearance has not been examined. Furthermore, the results of this new technique of nonsurgical ductal occlusion must be compared with the results of surgical techniques.

Color flow Doppler (CFD) is a sensitive technique for evaluating ductal shunting and the pulmonary arterial flow disturbances associated with it.5,6 With CFD, we prospectively evaluated the incidence and time course of residual ductal shunting after occlusion of the PDA with the Rashkind device. These observations were compared with those in a group of patients who had undergone surgical ductal ligation.

Methods

Patient Population

Between February 1986 and November 1988, 78 patients (group 1, 19 boys and 59 girls) underwent elective PDA closure with a Rashkind occluding device at the Hospital for Sick Children. Mean age at ductal occlusion was 4.5±4.0 years (range, 5 months to 18.5 years). Ninety-seven percent had isolated PDA, whereas one each of the remaining five patients had an atrioventricular septal defect, a complex univentricular heart for which a Fontan operation had been performed, an isolated perimembranous ventricular septal defect, pulmonary valve, and left pulmonary arterial stenosis.

Study Protocol

Before undergoing cardiac catheterization, each patient had an echocardiographic examination...
according to a specific protocol. Echocardiograms were done with an Ultramark 8 (ATL Inc) using 5- or 3.5-MHz transducers for imaging and pulsed wave Doppler and a 2.5-MHz nonimaging transducer for continuous wave Doppler. The HP 77020A ultrasound system (Hewlett-Packard) 5- and 3.5-MHz transducers were used for both conventional and CFD mapping of ductal flow. After complete evaluation of cardiac anatomy and function, ductal anatomy and blood flow were assessed using the high left parasternal view. Examinations were done serially at intervals of 1 day, 3 months, 6 months, and 1 year or more after ductal occlusion.

Control Population

Thirty children (group 2, nine boys and 21 girls; mean age, 5.7±4.9 years) who had undergone surgical ductal ligation between January 1982 and August 1988, at a mean age of 1.7±2.3 years, were prospectively evaluated in the same way by pulsed and CFD.

Doppler Examination

CFD was done in 49 (63%) patients both before and after ductal occlusion. All other patients who had undergone occlusion before availability of CFD in our laboratory (37%) (n=29) were evaluated by CFD in follow-up studies. CFD was performed using the high-speed turbulence mode (processing algorithm, 30/0/A/B/A) on the 77020A system, with electrocardiographic gating for assessing pulmonary arterial systolic and diastolic flow patterns. Color flow gains were standardized by the commonly used method of defining the point at which extraneous reverberation artifacts appeared and then turning down the gains until these artifacts disappeared. All recordings were performed at this level. The transducer was moved through multiple angles in the sagittal and axial planes in the high left parasternal view to ensure that small or eccentric jets were not missed.

Statistical Analysis

Results are expressed as mean±1 SD. Comparison of parameters between groups was done with one-way analysis of variance and Schéffe's F test to indicate significant differences at the level of 0.05 or less. The p value was then determined using the unpaired two-tailed t test. A statistically significant difference was when the p value was less than or equal to 0.05. Residual ductal shunting was evaluated with Kaplan-Meier product-limit analysis.9

Results

Prevalence of Residual Ductal Shunting

Group 1. The prevalence of residual ductal shunting from day 1 to more than 1 year by Kaplan-Meier product-limit analysis is shown in Figure 1. The prevalence fell from 38% on day 1 to 27% at 6 months. Another small spontaneous loss of residual shunting occurred between 6 months and 1 year resulting in a more-than-1-year residual shunting prevalence of 19.7% (confidence limits, 95±8%) with the largest drop in residual shunting occurring between day 1 and 6 months. Five of six patients underwent successful reocclusion of residual ductal shunts at a mean period of 12.8 months (range, 9–20 months) after occlusion. The results of reocclusion are not included in the previous analysis.

Group 2. Two instances of residual ductal shunting were encountered in group 2, in one patient within a few days, and in the second patient several years following ductal ligation, giving a prevalence of approximately 6%, which is significantly lower than that found after ductal occlusion (p<0.001). The duration of follow-up after ligation (44±58 months) was much longer, however, than after occlusion (9±7 months, p<0.0001).

Comparison Between Patients With and Without Residual Shunting

Table 1 shows that ductal size was significantly larger in patients with residual ductal shunting, whereas other parameters were similar. All but two shunts found by pulsed Doppler were later confirmed by CFD. Significantly more 17-mm prostheses were used in the group with residual shunting.

Characteristics of Residual Shunting

Color Flow Jets

A single jet was visualized over the superior aspect of the device in 25 of the 31 patients, whereas four patients had multiple discrete jets, and in two, the jets were inferiorly located. Figure 2 shows the characteristic position of the device within the ductus. In the most common type of residual shunting over the superior aspect of the device (Figure 3), the jet was directed toward the anterior wall of the main pulmonary artery as in
cases of isolated persistent PDA. In all patients, including the smaller infants, jets were better visualized with the lower carrier frequency (3.5 versus 5 MHz). More variance was also observed with the 3.5-MHz transducer.

Comparison between patients with persistent shunting and those in whom shunting resolved spontaneously within 3–6 months after occlusion showed no difference in area or direction of the color flow jet at serial studies. Of those resolving within 6 months of occlusion, one had multiple discrete jets, and the remainder had shunting over the device’s superior aspect.

**Clinical Evaluation (Murmur) for Residual Ductal Shunting**

A continuous murmur typical of ductal patency was found in 25% (six of 24) of patients with residual shunting 3 or more months after occlusion. Twenty-one percent (n=8) had grade 2/6 short systolic murmur only, whereas the remainder (54%) (n=13) had no detectable murmur. In contrast, 10 patients with no residual shunting had grade 2/6 short systolic murmurs. There appeared to be no characteristics of prosthesis position or site of residual shunting differentiating patients with continuous from those with soft systolic or no murmurs. Four of those with continuous murmurs were in the first cohort of 15 patients to undergo ductal occlusion at this institution.

**Main Pulmonary Arterial-Flow Patterns**

In patients and controls alike, systolic flow patterns consisted of a uniform blue within the main pulmonary artery, with a small area of red in its superior portion due to velocity aliasing. A characteristic early diastolic flow pattern consisting of brief transient retrograde flow at the inferior aspect of the main pulmonary artery was also present in both groups. On interrogation with pulsed Doppler, this diastolic flow was confirmed to be very brief in duration, and of low velocity. Residual ductal shunting, which showed both velocity aliasing and variance (mosaic color flow pattern) and also tended to occur along the anterior wall of the main pulmonary artery, was quite distinct from this flow pattern.

**Discussion**

Since the first successful transvenous ductal occlusion by Rashkind and Cuaso in 1979, the procedure has been applied in a select group of patients with isolated PDA, with complete occlusion rates of 60–80%. In animal experiments using this device, residual ductal shunting and factors that might be associated with it could not be evaluated. Complete endothelialization over the site of device implantation was virtually complete within 3 months of device implantation.

The true incidence of residual ductal shunting beyond the first few weeks after occlusion has not been clearly defined. Similarly, in the last major series of surgically treated PDA by Gross et al., the failure rate of ligation was not reported, and follow-up was based only on auscultatory findings. The efficacy of ductal occlusion with the Rashkind pro-

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**TABLE 1. Comparison of Parameters Between Patients With and Without Residual Ductal Shunts on Day 1 After Occlusion**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Residual shunt (n=30)</th>
<th>No residual shunt (n=48)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at occlusion (yr)</td>
<td>3.95±3.7</td>
<td>4.8±4</td>
<td>NS</td>
</tr>
<tr>
<td>Weight at occlusion (kg)</td>
<td>15±8.6</td>
<td>17.5±12</td>
<td>NS</td>
</tr>
<tr>
<td>Ductal luminal dimension (mm)</td>
<td>3.5±1.5</td>
<td>3±0.8</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>Ductal device size (pulmonary arterial orifice)</td>
<td>12 mm</td>
<td>21</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>17 mm</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

Device size refers to the diameter of the fully open "umbrella." The 17-mm device is the largest available. NS, not significant.
thesis must be compared with current surgical results using the same techniques of evaluation.

**Prevalence of Residual Ductal Shunting**

The majority of shunts detected by CFD were over the superior aspect of the occlusion device. This might be due to inferior tilting of the device because traction is applied on the releasing mechanism during occlusion, allowing the distal arms to sit in the aortic ampulla of the ductus. This might further explain the tendency for the proximal arms of the prosthesis to straddle the orifice of the left pulmonary artery. Better visualization of small PDA jets with the lower-frequency transducer is consistent with the CFD jet-size dependence on transducer-carrier frequency described in other lesions.13–15

The early shunt resolution might be related to endothelialization around the prosthesis as demonstrated in the animal experiments.11 The further shunt resolution after 6 months could have resulted from ongoing fibrosis and leads us to speculate that the prevalence of residual shunting might continue to decrease slowly at least within the first few years after ductal occlusion as suggested by the Kaplan-Meier analysis. Attempts to semiquantify ductal residual shunting at serial evaluations were not helpful in predicting resolution or persistence of shunting. This might be due to the small number of shunts resolving between day 1 and 6 months and the relatively long sampling intervals. Although analysis did not show significant association of residual ductal shunting with either age or weight at occlusion, the larger ductus had a higher chance of residual shunting. The same association with ductal device size would suggest that the larger occluding device was selected for occluding the larger ductus.

Although technical factors such as size of delivery sheath and risk of device embolization2 preclude ductal occlusion in infants less than 6 kg in weight or those with a large ductus (>9 mm in diameter), our data suggests that a ductus more than 5 mm in diameter, although associated with a higher risk of residual shunting, should still be occluded because of the significant rate of late spontaneous shunt resolution. The feasibility, role, and success rate of repeat closure attempts after initial unsuccessful occlusion need further evaluation.

Although serial evaluation of patients following ductal ligation has not been performed, the late residual shunting rate of 6% in this series probably overestimates the true prevalence, due to the small patient numbers. It would appear that late (>1 year) ductal residual shunting is much less common after surgical ligation than it is after occlusion. It must be emphasized however that the results of occlusion after more than 1 year are based only on a subset of the patient population in this study and can be expected to be different when the number of patients followed for more than 1 year is larger.

**Significance of Residual Shunting**

The main reason for ductal closure in the setting of the isolated small PDA is to avoid the risk of bacterial endarteritis.16 In some of these patients, however, an additional reason was the elimination of a symptomatic large left-to-right shunt. In all such patients, symptoms were ameliorated with a gradual return of cardiac size to normal. Residual shunting was not associated with symptoms in any patient, including those with continuous murmurs. The unresolved problem is, therefore, the risk of bacterial endarteritis in this unique population.
Although recent reviews\(^\text{17,18}\) show changes in the characteristics of bacterial endocarditis compared with the preantibiotic and presurgical era, PDA still exists as a cause of endarteritis, particularly in an elderly population.\(^\text{19}\) The major site of endarteritis is in the main pulmonary artery at the site where the high velocity jet strikes the arterial wall.\(^\text{20,21}\) In considering the relative risk of endarteritis in patients with persistent residual shunting, the jet velocity might be a factor,\(^\text{22}\) as most of the color flow jets were of high velocity when interrogated by pulsed Doppler. A minority, however, were small and not mosaic, and could not be consistently demonstrated by simultaneous pulsed Doppler. We currently recommend continued observance of prophylaxis against endarteritis at times of increased risk in all patients with residual ductal shunting of any magnitude.

The absence of a typical murmur of a PDA in patients with residual shunting after occlusion suggests that clinical findings alone cannot be relied on for this purpose. This phenomenon is likely related to the amount of shunting present. We now depend entirely on CFD evaluation for detection of residual ductal shunting. Transient retrograde diastolic flow at the inferior aspect of the main pulmonary artery, reported in normal subjects and observed in this study population, should not be confused with residual ductal shunting because the latter is high velocity and present throughout most of diastole.

### References


**KEY WORDS** • echocardiography, Doppler • echocardiography, two-dimensional • occlusion
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