Transfemoral Plug Closure of Patent Ductus Arteriosus
Experiences in 61 Consecutive Cases Treated Without Thoracotomy

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SUMMARY
We successfully closed the isolated patent ductus arteriosus in 58 of 61 consecutive patients using the transfemoral-catheter method originally introduced by Porstmann in 1968. To perform this technique more safely and reliably, some instrumental and technical improvements were made. The indications for this method have been expanded to include the cylindrical or window-type ductus as well as the conical-shaped ductus. Classification into three groups of the configuration of the ductus by angiography has been useful in selecting the shape of the closing plug.
Whenever feasible, we consider the catheter technique to be the method of choice to close the ductus.

Additional Indexing Words:
Porstmann’s method Classification of patent ductus arteriosus Closing plug configuration

In 1966, Porstmann1,2 was the first to successfully apply a new method by which a patent ductus arteriosus (PDA) was closed by a plug transported by catheters through the femoral artery. Thereafter, he reported successful procedures in 56 of 62 patients. Takamiya3 had used this method in ten patients by October, 1971. Lack of mortality, minor morbidity, and no recurrence of shunting in their long-term follow-up studies encouraged us to use this method in our patients.4

To date, we have successfully accomplished the transfemoral plug closure of PDA in 58 of 61 patients. Though the principle of the method has been unaltered, as our experience broadened the technical details were modified. The purpose of this report is to describe our experiences with this new method.

Material and Methods
Nonsurgical transluminal ductus closure was attempted in 61 patients, 14 males and 47 females, ranging from three to 98 years of age (table 1). There was no particular method for selecting candidates, except for the size and age of the patients and the shape and size of the ductus. All patients underwent ductus and femoral artery angiography in advance to evaluate the shape and the relative sizes of the lumens. The diameter of the plug should be 20–40% larger than that of the ductus. Particular attention was given to ruling out all other associated heart anomalies.

The principle of Porstmann’s method is as follows (fig. 1). A long catheter is inserted through the femoral artery, up the aorta, and across the ductus. The arterial catheter is caught in the right heart by a catching wire and catheter, passed through a femoral vein. The arterial catheter is then drawn by the venous catheter through the right heart, down the inferior vena cava, and out the femoral vein. A long, steel guide wire, lying within the lumen of the above-mentioned arterio-transductal-venous catheter loop, serves as a track over which a closure plug will be guided into the ductus from the aortic side. The plug, which is made of Ivalon foam plastic, is conical in shape and is stabilized by an inner steel-wire frame.

The plug is introduced through a tubular applicator and threaded over the track wire. After complete closure is achieved with the aid of the pushing catheter, the steel wire (track wire) is withdrawn from the venous side. The plug remains wedged in the no-longer-patent ductus (fig. 2).

Although the principle of Porstmann’s method has not been altered, the following technical modifications were made as our experience progressed.

Modification of the Closing Plug
Before the plug is boiled for sterilization, a short steel wire of the same caliber as the transductal arteriovenous track wire is placed in the center of the frame (fig. 3). This process insures an adequate opening for insertion of the track wire into the center of the plug during the procedure, as well as
facilitating easy withdrawal of the wire after plug placement. This prevents the plug from sliding into the pulmonary artery.

Modification of Insertion of Closing Plugs via the Femoral Artery

When this procedure is done by the percutaneous method, the thin-walled teflon tube of the applicator is inserted percutaneously into the femoral artery with the aid of a telescopically fitted coaxial inner tube. Blood spurts when the inner tube is replaced by a rubber plug and when the latter is replaced by the closing plug (fig. 4, left). Excessive bleeding is prevented when the femoral artery is exposed surgically by the following modified technique (fig. 4, right). The tapered tip of a thin-walled teflon tube of the applicator, without inner components, is inserted into the exposed femoral artery with a closing plug placed in the metal funnel by means of a strong 25 cm blunt-ended needle (pushing pipe) traveling on the wire.

Test Injection from Venous Side

Complete closure of the duct with a plug is confirmed by phonocardiography, dye dilution study, and the injection of contrast material through a thrust catheter into the aorta at the base of the seated plug. The position of the closing plug is again confirmed by test injection, through the loop catheter, in the pulmonary artery at the tip of the seated plug. This is particularly important when a dumb-bell-shaped plug is used for the window-type ductus.

Results

Complete closure of PDA was achieved in 58 of 61 patients (95%). In three patients, the transfemoral closure had to be abandoned because the ductus was so distensible the plug passed through the ductus while the track wire was being pulled out; the plug was removed from the femoral vein along the track wire. Later, one of these patients was treated surgically, and the remaining two patients are awaiting surgical treatment. The plug fell back into the aorta during the procedure in three patients; in one of them the plug was removed from the artery and the duct was replugged on another day. In the remaining two, the duct was replugged before the removal of the plug from the artery. One of these patients developed acute renal failure with satisfactory recovery a month later. Excluding this patient, there were no complications or mortality in the current series of 61 consecutive patients. All of the patients have been closely followed, and up to two and one-half years, no plugs have been displaced.

Although the simple ductus is basically conical in shape, the exact shape and size of the ductus and the aortic infundibulum vary widely in each patient. The configuration of the ductus must be established by aortography (fig. 5, table 2). Group 1 (conical type) includes the cases of a conical or cylindrical ductus with a deep infundibulum. Group 2 (cylindrical type) includes cases of a cylindrical ductus with a shallow infundibulum. Group 3 (window-type) includes the cases of a short ductus with a shallow infundibulum.

The morphological condition in which the ductus and the aortic infundibulum were conical in shape (group 1) was the original requirement for successful closure. However, the technical modifications described above have made it possible to close a cylindrically-shaped ductus (group 2) by using modified plugs of a long-nosed shape and a window-type ductus (group 3) by using modified plugs of a dumb-bell shape (fig. 3).

Discussion

The transfemoral approach (Porstmann’s method) is less complicated than thoracotomy because it is carried out under local anesthesia except in younger children and leaves no large operative scar on the chest. The absence of a scar is desirable because patent ductus arteriosus is more common in females.
It is difficult to make a closing plug in which the diameter of the base is less than 3 mm. For this reason, candidates for ductus closure by this method should have a femoral artery greater than 3 mm in diameter. Generally speaking, the patients over three years of age meet this requirement. Porstmann\textsuperscript{1} has successfully applied this method in patients older than five years and Takamiya\textsuperscript{3} in patients over seven years.

We have performed this method successfully on two three-year-old and three four-year-old patients.

A closing plug of adequate size must be selected for each patient. The plug is made of a fine textured ivalon which is compressed against the central frame in a ratio of 5 or 6 to 1. We designed a plug of suitable size and shape for each ductus. The diameter of the plug should be 20–40% larger than that of the ductus shown by aortography. When a plug is too small for the ductus or the distensibility of the ductus is too great, the plug may slip into the pulmonary artery. If this occurs, the plug can be easily removed from the femoral vein along the guide wire followed by a thrust catheter. On the other hand, when the plug is too large or the ductus is too rigid to accept the plug, difficulties of stable insertion of the plug into the ductus occur, and the plug may fall back into the aorta after the track wire has been removed. This is the most serious problem with this method. In this series of 61 patients, there were three such incidents, whereas Porstmann\textsuperscript{1} reported two of 62 patients and Takamiya\textsuperscript{3} reported one of 28 cases. When the plug becomes lodged around the aortic bifurcation, we usually try to plug the ductus with the second plug before removal of the first. However, if the plug lodges further up in the abdominal aorta, the plug should be removed first to prevent renal ischemia, which occurred in one of our patients. The embolizing plug in the aorta can be pulled down into the femoral artery by a balloon catheter (Fogarty), and can be removed by arteriotomy, as in the usual case of em-
bolectomy. However, in a few cases, surgical removal of the lodged plug from the abdominal aorta may be indicated.

Porstmann\textsuperscript{1} reported that the diameter of the ductus should be less than that of the femoral artery. However, we believe that a plug larger than the artery, measured by angiography, can be inserted by the use of a well-fitting, thin-walled teflon tube placed meticulously, under direct vision, into the surgically exposed femoral artery. Successful closure by this method has been accomplished in two of 61 patients whose measured diameter of the ductus was larger than that of the teflon tube. A large duct, when compared to the size of the femoral artery, is not an indication for this method at this time. Further modification of the technique or the creation of different types (shape and material) of closing plugs may allow for closure of the oversized ductus.\textsuperscript{6}

According to Porstmann,\textsuperscript{1} the ivalon foam plastic

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**Table 2**

<table>
<thead>
<tr>
<th></th>
<th><strong>Group 1</strong></th>
<th><strong>Group 2</strong></th>
<th><strong>Group 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ductus</strong></td>
<td>Conical</td>
<td>Cylindrical</td>
<td>Short</td>
</tr>
<tr>
<td><strong>Infundibulum</strong></td>
<td>Deep or shallow</td>
<td>Deep</td>
<td>Shallow</td>
</tr>
<tr>
<td><strong>Patients (%)</strong></td>
<td>52 (85)</td>
<td>8 (13)</td>
<td>1 (2)</td>
</tr>
</tbody>
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**Figure 5**

Aortographic classification of PDA and morphological features (see table 2).

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**Figure 4**

Method to introduce a closing plug into the artery. Percutaneous approach originally invented by Porstmann (left panel). Modified technique when the artery is exposed (right panel). When the modified technique is applied under surgical exposure of femoral artery, bleeding procedures of the percutaneous method (left, between A, B, and C) are not necessary. Bleeding during procedures D-F is negligible since the closing plug is now located in front of the teflon tube of the applicator. Abbreviations: dotted catheter = arterio-transductal-venous loop catheter; hatched catheter = thrust catheter; hatched tube = inner component of the applicator; black pipe = pushing pipe (hypodermic needle) which is removed and replaced by the pushing catheter.
plug will become infiltrated with cells a few days after placement in the ductus, and in a few months the host's connective tissue will effect a permanent closure of the ductus. Therefore, there would be no foreseeable problems due to the placement of the ivalon plug inside the ductus, and we have not seen any problems in the follow-up period lasting up to two and one-half years. A recurrence of shunting has not been observed in any of our patients.

References
Transfemoral plug closure of patent ductus arteriosus. Experiences in 61 consecutive cases treated without thoracotomy.
K Sato, M Fujino, T Kozuka, Y Naito, S Kitamura, S Nakano, C Ohyama and Y Kawashima

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