Transcatheter Occlusion of Patent Ductus Arteriosus With Adjustable Buttoned Device
Initial Clinical Experience

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Background. Several devices are available for transcatheter occlusion of patent ductus arteriosus. Most of these devices either require complicated intracardiac maneuvering, have not been tried in humans, or need a large-sized sheath for implantation of the device.

Methods and Results. During a 26-month period ending November 1992, 14 patients underwent transcatheter closure of patent ductus arteriosus with an adjustable buttoned device delivered via a 7F sheath under an institutional review board–approved custom-made device protocol. The children were 15 months to 8 years of age with weight range of 7.2 to 19 kg. The patent ductus arteriosus measured from 2 to 7.5 mm (median, 3 mm) at the narrowest diameter and was conical, short, or tubular. They were occluded with devices measuring 15 to 20 mm. The ratio of pulmonary to systemic flow decreased (P < .01) from 1.9 ± 0.6 (mean ± SD; range, 1.3 to 3.2) to 1.05 ± 0.1 (1 to 1.3). Continuous murmur of patent ductus arteriosus disappeared in all except 1 patient. Small residual shunts were detected by color Doppler studies in 4 of 14 patients (29%). All patients were followed for 1 to 24 months (mean, 6 ± 7 months). The device was intact in all patients, and no breakage of the wires was noted. No shunts were seen in 12 of 14 patients (86%), and minute residual shunts were seen in 2 children. No major complications were encountered.

Conclusions. It is concluded that transcatheter closure of patent ductus arteriosus with the adjustable buttoned device is feasible and effective and can be accomplished via small 7F sheaths; a 7F sheath is adequate for all ductal sizes; and the adjustable length of the loop accommodated all types of patent ductus arteriosus. Clinical trials on a larger number of patients are warranted. (Circulation. 1993;88:1119-1126.)

Key Words • prosthesis • occlusion • heart defect • pediatrics

Surgical closure of patent ductus arteriosus is a conventional treatment option to occlude this lesion. The mortality rate for surgical closure is negligible. However, the morbidity of anesthesia and thoracotomy, scar of surgery, and expense are disadvantages. During the past 25 years, Porstmann and colleagues1,2 and Rashkind and colleagues3-6 have developed transcatheter methods to close the patent ductus arteriosus. A double-disc, nonhooked prosthesis5,6 was used in several clinical trials by several groups of researchers.6-12 Although these methods have advantages over the surgical closure, the delivery catheters/
Patients were selected on the basis of standard criteria established for selection of patients for surgical treatment of patent ductus arteriosus. Only patients with clinical and laboratory features, including echocardiographic-Doppler studies, suggesting the need for surgical correction were chosen. No patients were excluded because of ductal size or anatomy.

The buttoned device system consists of three components: the occluder, the counter-occluder, and a delivery system, and is similar to the device used for occlusion of atrial septal defect.\textsuperscript{14-17} The occluder is made of a Teflon-coated wire skeleton covered with \textfrac{1}{8} in. polyurethane foam. The wire skeleton is \texttimes\texttimes-shaped when unfolded; the wires can be made to position parallel for introduction into a 7F sheath. An important difference between this and the atrial septal defect device is the button loop. The length of the loop is 8 mm instead of a 2-mm loop. There are two knots (4 mm and 8 mm from the occluder) with incorporation of radiopaque material into the proximal knot (the knot farthest from the occluder) (Fig 1). The counter-occluder is made up of a single-strand, Teflon-coated wire skeleton covered with a rhomboid-shaped polyurethane foam. A rubber piece is sutured in its center and becomes a buttonhole (Fig 1). The device delivery system consists of (1) a Teflon-coated 0.035-in. guidewire (Cook, Inc, Bloomington, Ill), the loading wire, and (2) a folded 0.008-in. Nylon thread passing through the guidewire after having its core removed. This thread passes through the loop in the center of the occluder. The device is delivered through a 7F, long sheath (Cordis Corp, Miami, Fl, or Cook Inc). A 7F multi-A2 (Cordis) catheter (pusher) is used to advance the occluder and counter-occluder within the sheath.

The patients were sedated with a mixture of meperidine, promethazine, and chlorpromazine. This is supplemented with intermittent doses of midazolam to ensure adequate sedation. No general anesthesia was used in patients undergoing patent ductus arteriosus closure in the United States and in Brazil. General anesthesia was used in European patients. Arterial pressure, oxygen saturation by pulse oximetry, and heart rate by ECG were monitored throughout the procedure. Complete cardiac catheterization via femoral vein and artery percutaneously was performed to confirm the clinical diagnosis and to exclude other cardiac defects. Aortic angiography in posteroanterior and lateral views was obtained by a retrograde arterial catheter or by antegrade introduction of an angiography catheter via the patent ductus arteriosus. In the latter situation, balloon occlusion angiography\textsuperscript{18} was performed (Fig 2A). Heparin (100 units/kg) was given intravenously. Initially, a 5F or 6F multi-A2 (Cordis) catheter is positioned transvenously in the descending aorta across the patent ductus arteriosus. A 0.035-in. exchange guidewire then is positioned in the descending aorta, and the catheter is removed. A 7F multi-A2 catheter (Cordis) and a 7F sheath (Cordis or Cook) were advanced over the guidewire with their tips positioned in the descending aorta. The catheter and the guidewire were removed, and the sheath was clamped to prevent back bleeding. The occluder component of the device was then folded and positioned in the sheath, and a 7F end-hole catheter was advanced into the sheath over the guidewire of the delivery system. Advancing the catheter within the sheath pushes the device toward the descending aorta. Once the device was across the ductus, but still within the

![Fig 1. Drawing of the adjustable button device. The occluder (Occ) is composed of an \texttimes\texttimes-shaped wire skeleton covered with \textfrac{1}{8} in. polyurethane foam. An 8-mm string loop is attached to the center of the occluder. The loop has two knots; the first knot (close to the occluder) is not radiopaque (NRB), whereas the second knot (farthest from the occluder) is made radiopaque (RB). A folded 0.008-in. nylon thread (NT) passes through a hollow loading wire (LW) after having it passed through the loop in the center of the occluder. The counter-occluder (COc) consists of a single strand, Teflon-coated wire skeleton covered with a rhomboid-shaped polyurethane foam with a rubber piece (RP) sutured in its center. During the implantation of the device, the COc can be positioned between NRB and RB (for long ductuses) or between NRB and Occ (for short ductuses). The components of the device were not drawn to scale.](image-url)
sheath, the sheath was slowly withdrawn into the ductus, thus opening the occluder in the descending aorta at its junction with the ductus. The entire system was slowly withdrawn to ensure anchoring of the occluder on the descending aortic side of the ductus. Once in position, the sheath and the catheter tips were withdrawn into the main pulmonary artery. The catheter was removed while maintaining the tip of the sheath in the main pulmonary artery. The counter-ocluder was then threaded over the guidewire, but within the sheath, and was delivered to the pulmonary artery side of the patent ductus arteriosus. Introduction of the knot (button) of the occluder loop through the rubber piece (buttonhole) of the counter-ocluder was performed by simultaneously (gently) pulling the occluder against the ductus while advancing the counter-ocluder with the long sheath. Verification that the knot has been pulled through the buttonhole was obtained by fluoroscopy aided by the radiopaque marker on the knot. Further pushing of the counter-ocluder with the tip of the sheath while gently pulling the occluder was attempted in short ductuses so that the counter-ocluder could pass beyond the non-opaque distal knot (closer to the occluder). After satisfactory buttoning, the loading wire was cut at the tip and withdrawn, leaving the nylon strands holding the occluder. The device was disconnected by pulling one of the two nylon strands, thus disconnecting the implanted device from the loading system. During both of these maneuvers, the long sheath was gently pressed against the device to prevent inadvertent dislodgment of the device. The long sheath was removed and replaced with a short, regular sheath in the femoral vein. Fifteen minutes after device implantation, oxygen saturation data and an aortic arch cineangiogram were recorded. Cefazolin (50 mg/kg) was administered intravenously and repeated at 6 and 12 hours after the procedure. Catheters and sheaths were removed, taking adequate precautions not to dislodge the device. Oral aspirin (3 to 10 mg·kg⁻¹·day⁻¹) was begun on the day after device implantation for preventing excessive aggregation of platelets on the device. Aspirin was discontinued 6 weeks later. Two-dimensional echocardiographic and Doppler (pulsed and color) studies were performed on the afternoon of the procedure; 1, 6, and 12 months following the procedure; and yearly thereafter.

The data are expressed as mean±SD. The Student's t test was used for comparison of the preclosure and postclosure echocardiographic measurements. The level of statistical significance was set at P<.05.

Results

During a 26-month period ending November 1992, 14 patients underwent transcatheter closure of their patent ductus arteriosus at four institutions (Table 1). Their ages ranged from 15 months to 8 years with a median age of 2.5 years (Table 2). They weighed between 7.2 and 19 kg with a median of 10.2 kg (Table 2). One of these children has previously been reported.19

The patent ductus arteriosuses measured 2 to 7.5 mm in diameter at their narrowest diameter (Table 2). The ratio of pulmonary to systemic flow (Qp:Qs), measured in nine children, was 1.9±0.6 and varied between 1.3 and 3.2. Two infants were in congestive heart failure and failed to thrive, and one child had recurrent lower respiratory tract infection; other children had asymptomatic murmurs. Thirteen children had no previous interventions. The remaining child had a Rashkind patent ductus arteriosus occluder placed across the ductus 1 year previously but still had a residual shunt. The size of the device implanted across the patent ductus arteriosus varied between 15 and 20 mm. The duration of the procedure excluding the diagnostic study varied between 15 to 30 minutes. Similarly, the fluoroscopy time on average was 10 minutes longer than the diagnostic study.
Table 2. Data on Patients Undergoing Transcatheter Occlusion of Patent Ductus Arteriosus

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>(Q_p:Q_s) Before</th>
<th>(Q_p:Q_s) After</th>
<th>Murmur</th>
<th>Size of PDA (mm)*</th>
<th>Ductal type</th>
<th>Size of device (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.0</td>
<td>19.0</td>
<td>1.4</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>2.6</td>
<td>Conical</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>9.9</td>
<td>1.3</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>2.0</td>
<td>Tubular</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>14.1</td>
<td>1.4</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>2.0</td>
<td>Conical</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>7.2</td>
<td>3.2</td>
<td>1.3</td>
<td>P</td>
<td>A</td>
<td>5.0</td>
<td>Tubular</td>
</tr>
<tr>
<td>5</td>
<td>1.25</td>
<td>8.7</td>
<td>1.8</td>
<td>1.2</td>
<td>P</td>
<td>A</td>
<td>4.0</td>
<td>Conical</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>8.0</td>
<td>NM</td>
<td>NM</td>
<td>P</td>
<td>A</td>
<td>2.5</td>
<td>Tubular</td>
</tr>
<tr>
<td>7</td>
<td>3.0</td>
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<td>P</td>
<td>A</td>
<td>3.5</td>
<td>Short</td>
</tr>
<tr>
<td>8</td>
<td>1.3</td>
<td>10.0</td>
<td>NM</td>
<td>NM</td>
<td>P</td>
<td>A</td>
<td>2.5</td>
<td>Rashkind occluder</td>
</tr>
<tr>
<td>9</td>
<td>3.5</td>
<td>15.0</td>
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<td>NM</td>
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<td>A</td>
<td>4.0</td>
<td>Tubular</td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
<td>9.0</td>
<td>2.2</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>3.0</td>
<td>Conical</td>
</tr>
<tr>
<td>11</td>
<td>7.0</td>
<td>16.0</td>
<td>2.0</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>2.0</td>
<td>Tubular</td>
</tr>
<tr>
<td>12</td>
<td>5.0</td>
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<td>1.7</td>
<td>1.0</td>
<td>P</td>
<td>A</td>
<td>5.0</td>
<td>Short</td>
</tr>
<tr>
<td>13</td>
<td>8.0</td>
<td>19.0</td>
<td>2.0</td>
<td>1.0</td>
<td>P</td>
<td>P</td>
<td>7.5</td>
<td>Short</td>
</tr>
</tbody>
</table>

\(Q_p:Q_s\) indicates pulmonary-to-systemic flow ratio; PDA, patent ductus arteriosus; P, present; A, absent; and NM, not measured.

*Size measured at its narrowest diameter.

After implantation of the device, oxygen saturation data (in 9 children) and angiography (in all children) revealed no residual shunting in 10 of 14 children (71%); minimally detectable shunts were seen in the remaining four children. The \(Q_p:Q_s\) decreased from 1.9±0.6 to 1.05±0.1 \((P<.01)\). Although we have demonstrated a decrease in \(Q_p:Q_s\) after device implantation, we recognize that quantitation of shunt across the ductus by calculation of \(Q_p:Q_s\) is notoriously inaccurate. Aortic arch angiography revealed no residual shunt (Figs 2 through 4) in 10 patients, and faint opacification of the pulmonary artery was seen in the remaining 4 children. Closure of the patent ductus arteriosus was accomplished successfully in all types of ductus (Table 2, including tubular (Fig 2), conical (Fig 3), and short or "aortopulmonary window" (Fig 4) types. One patient with residual shunt following previous Rashkind device also underwent successful closure with the adjustable buttoned device (Fig 5). Careful auscultation following device implantation revealed no residual murmurs in 13 children; all of these children had grade II-III/VI continuous murmurs before transcatheter occlusion. One child had a faint, continuous murmur (Table 2). Echo-Doppler studies performed on the afternoon of device implantation revealed mild color flow disturbances in the pulmonary artery suggestive of small residual patent ductus arteriosus in 4 children (Table 3), the same children with residual shunt by oximetry and angiography. The size of the left atrium (2.3±0.46 vs 2.0±0.31 cm, \(P=.05\) to .1), the ratio of the left atrium to the aortic root (1.5±0.3 vs 1.2±0.2, \(P<.01\)), and the left ventricular end-diastolic dimension (3.2±0.27 vs 2.9±0.22 cm, \(P<.01\)) decreased after patent ductus arteriosus occlusion. The left ventricular shortening fraction (41±4 vs 39±5, \(P>.1\)) remained unchanged.

There were no significant complications, although transient arrhythmia (while traversing right ventricular outflow tract with the sheath) occurred in some patients and bleeding requiring transfusion occurred in one patient. In three patients, the Cordis sheath kinked at the pulmonary end and had to be replaced with a 7F Cook sheath. The devices were withdrawn and reintroduced without any problem. No unbuttoning was noted.

All patients were discharged home within 24 hours of the procedure. Review of aortograms and pulmonary artery angiograms did not reveal any evidence for aortic and left pulmonary artery obstruction.

Follow-up data are available in all children (range, 1 to 24 months; mean, 6±7 months) following patent ductus arteriosus closure. All children with symptoms improved, including the two children with congestive heart failure. Both of these children gained weight, and their weight percentiles increased from below the 5th percentile to the 50th percentile. None of the children, including the child who had residual murmur immediately after device placement, had any residual murmurs. The device was seen to be in position both on chest roentgenograms and on two-dimensional echocardiographic studies. No breakage of the radiopaque components of the device was seen on chest radiography. Minute residual shunt was seen on color Doppler study in 2 of the 14 children (14%) at follow-up (Table 3). In 2 children in whom a small shunt was detected immediately following transcatheter occlusion, no residual shunt was observed at the follow-up color Doppler study. The size of the left atrium (2.0±0.2 cm), ratio of left atrium to aortic root (1.2±0.2), left ventricular end-diastolic dimension (3.1±0.2 cm), and left ventricular shortening fraction (40±4) remain unchanged \((P>.1)\) compared with the immediate postocclusion echocardiographic values. There was no echocardiographic or Doppler-demonstrable evidence for obstruction in the descending aorta and left pulmonary artery. No complications were encountered during the follow-up period.

Discussion

Feasibility of transcatheter occlusion of patent ductus arteriosus was demonstrated by Porsmann and colleagues, and by Rashkind and colleagues. However,
the delivery catheters are large and bulky and required
insertion of 13F to 28F sheaths into the femoral artery
for implantation of Portsmann's Ivalon plug and
insertion of 8F to 11F sheaths into the femoral vein for
placement of Rashkind's double-disc device. Although much improved, the 8F sheath, and certainly the
11F, is too bulky for use in infants and small children.
Sideris and colleagues developed a buttoned device
for closure of atrial septal defect. This device was
modified by us into an adjustable button device for
occluding the patent ductus arteriosus. These devices
require a small sheath (7F) for delivery and can be used
to close patent ductus arteriosuses of different lengths.
This device was initially used in experimental patent
ductus arteriosus in piglets with success, and subse-
sequently, we reported its successful use in a 5-year-old
child. The device can easily be delivered through a 7F
sheath, thus making it more suitable in younger and
smaller children, and it may have advantages over the
other devices.

The adjustable device has a longer button loop (8
mm) with a radiopaque marker at the end (Fig 1). In
addition to this, there is another knot in the middle (Fig
1, nonradiopaque button). Therefore, patent ductus
arteriosuses of various lengths and shapes, namely, the
conical type, tubular, and short ("aortopulmonary win-
dow") ductuses can be effectively occluded with this
device. The patent ductus arteriosuses that are not
suitable (eg, short ["aortopulmonary window"] and
tubular) for transcatheter occlusion by the Rashkind
device can be occluded with the adjustable buttoned
device. This device can be used for all sizes of ductuses,
whereas the Rashkind device is not suitable for patent
ductus arteriosuses larger than 7 mm. An additional
advantage of the buttoned device is that it is positioned
outside the ductus, totally isolating the entire ductus
from circulation. Because of the small sheath required
for device implantation and adjustability of the device
to effect closure of all types of patent ductus arteriosus,
the adjustable buttoned device conceivably could
be applicable for closure of the patent ductus arteriosus
in all age groups and for all types of patent ductus
arteriosuses.

Rapid reduction of the size of the left atrium and left
ventricle by echocardiography is consistent with reduc-
tion of left-to-right shunt. Persistence of small residual
shunts immediately after device placement in 29% of
the patients (4 of 14) is of concern. However, in 2 of the
4 patients, the shunts (which were present immediately
after device implantation) disappeared on follow-up.
This is similar to the reduction in percent of residual
shunts following implantation of Rashkind's device, as
observed by Musewe and colleagues. Because of the
lack of murmurs and because of reduction in the left
atrial size, these shunts are small and probably are of no
concern. Progressive endothelialization may result in
further closure of the residual defects.

Encroachment of the ostium of the left pulmonary
artery, causing obstruction to flow, reported with Rash-
kind's device was not seen in this small series. This is
probably related to the less bulky nature of the counter-
occluder that is on the pulmonary arterial end of the
ductus.
Several other types of devices are available for transcatheter closure. The dumbbell-shaped plug of Mills and King, Ivalon sponge plugs sutured onto stainless-steel umbrellas of Leslie and colleagues, detachable silicone double balloon of Warnecke and associates, nylon sack filled with segments of modified guidewire of Magal and colleagues, and a temperature-shape changeable-shape memory polymer (polynorbornene) of Echigo and coworkers have been used to occlude experimental patent ductus arteriosuses in animal models. Delivery of the closure device in most of these methods is through large-size delivery catheters. Furthermore, to the best of our knowledge, no human application of these techniques is reported.

In summary, there are several devices available for transcatheter occlusion of patent ductus arteriosus. Most of these devices either require complicated intracardiac maneuvering, have not been tried in human subjects, or need a large-sized sheath for implantation of the device. The recently described adjustable buttoned device can be delivered across the patent ductus arteriosus via a 7F sheath and had undergone successful trials in animal models and now some clinical applications in a small number of patients. Because of the ease of the device implantation, the requirement for a smaller-sized sheath for delivery, and adjustability of the device to varying lengths of patent ductus arteriosus, we believe that this adjustable buttoned patent ductus arteriosus device has good potential and that further clinical trials are warranted. Further improvement in the device may eventually result in extending the procedure to close patent ductus arteriosuses in younger babies, including neonates and premature infants.

### Table 3. Color Doppler Shunt Before and After PDA Occlusion

<table>
<thead>
<tr>
<th>Patient</th>
<th>Before closure</th>
<th>Immediately after closure</th>
<th>Duration of follow-up (mo)</th>
<th>At last follow-up</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>PDA</td>
<td>None</td>
<td>24</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>PDA</td>
<td>None</td>
<td>12</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>PDA</td>
<td>None</td>
<td>12</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>PDA</td>
<td>Small</td>
<td>13</td>
<td>Trivial</td>
</tr>
<tr>
<td>5</td>
<td>PDA</td>
<td>Trivial</td>
<td>7</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>PDA</td>
<td>Trivial</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>PDA</td>
<td>None</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>PDA</td>
<td>None</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>PDA</td>
<td>None</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>PDA</td>
<td>None</td>
<td>1</td>
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</tr>
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<td>None</td>
<td>1</td>
<td>None</td>
</tr>
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<td>None</td>
<td>1</td>
<td>None</td>
</tr>
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<td>PDA</td>
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<td>None</td>
<td>1</td>
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</tr>
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</table>

PDA indicates ductus arteriosus.
Addendum

Since the preparation of the manuscript, 21 additional patients (total of 35) underwent transcatheter occlusion of patent ductus arteriosus. Successful device implantation was feasible in 34 patients (97%). In the lone exception, the device was inadvertently dislodged while disconnecting the nylon thread, but the device was extracted out of the patient transvenously. In the remaining 34 patients, immediate and follow-up results remain similar to those of the first 14 patients.

Acknowledgments

Supported in part by National Institutes of Health grant RR-03186 from the Division of Research Resources to the University of Wisconsin Medical School, a grant-in-aid of the Graduate School, University of Wisconsin-Madison, and a grant from Oscar Rennbohm Foundation, Inc, Madison, Wis.

References


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Circulation. 1993;88:1119-1126
doi: 10.1161/01.CIR.88.3.1119
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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