Treatment Options for Pediatric Patent Ductus Arteriosus
Systematic Review and Meta-analysis

Jennifer Y. Lam, MD; Steven R. Lopushinsky, MD; Irene W. Y. Ma, MD, PhD; Frank Dicke, MD, MBA; and Mary E. Brindle, MD, MPH

BACKGROUND: Patent ductus arteriosus (PDA) in the nonpremature pediatric patient is currently treated by surgical ligation or catheter occlusion. There is no clear superiority of one technique over the other. This meta-analysis compares the clinical outcomes of the two treatment options for PDA.

METHODS: We performed a literature search of MEDLINE, Embase, PubMed, and the Cochrane database of randomized controlled trials (RCTs) that took place between 1950 and February 2014 and hand-searched references from included studies. We excluded studies of adult or premature patients and those without a direct comparison between surgical and catheter-based treatments of PDAs. Outcomes of interest were reintervention, total complications, length of stay, and cost.

RESULTS: One thousand three hundred thirty-three manuscripts were screened. Eight studies fulfilled the inclusion criteria (one RCT and seven observational studies [N = 1,107]). In pooled observational studies, there were significantly decreased odds (OR, 0.12; 95% CI, 0.03-0.42) for reintervention in the surgical ligation group but insignificantly higher odds for overall complications (OR, 2.01; 95% CI, 0.68-5.91). There were no complications reported in the RCT, but surgical ligation was associated with decreased odds for reintervention and a longer length of stay. Funnel plots revealed a possible publication bias and a quality review identified comparability bias.

CONCLUSIONS: Both therapies have comparable outcomes. Reintervention is more common with catheter-based treatment, but overall complication rates are not higher and hospital stay is shorter. Our data span >2 decades and may not reflect current surgical and catheterization outcomes. Large, randomized, prospective studies may help determine the optimal treatment strategy.

FUNDING/SUPPORT: The authors have reported to CHEST that no funding was received for this study.

CORRESPONDENCE TO: Mary E. Brindle, MD, MPH, Department of Surgery, Division of Pediatric General Surgery, University of Calgary, 2888 Shaganappi Trail NW, Calgary, AB, T3B 6A8, Canada; e-mail: maryebrindle@gmail.com

© 2015 AMERICAN COLLEGE OF CHEST PHYSICIANS. This is an open access article distributed under the terms of the Creative Commons Attribution-Noncommercial License (http://creativecommons.org/licenses/by-nc/3.0/), which permits unrestricted use, distribution, and reproduction to noncommercial entities, provided the original work is properly cited. Information for reuse by commercial entities is available online.

DOI: 10.1378/chest.14-2997
Patent ductus arteriosus (PDA) is one of the most common congenital heart diseases.\(^1\) Although small PDAs may be asymptomatic, larger ones can result in clinically significant complications.\(^1\) PDAs that are large, symptomatic, or persistent despite medical therapy require procedural intervention. Thoracotomy has remained the standard for treating PDAs since it was first performed in 1938.\(^2,3\)

In recent years, minimally invasive methods to obliterate PDA have been developed. Video-assisted thoracoscopic surgery (VATS) was applied to the treatment of PDAs in 1991.\(^4\) Cardiac catheterization, first used to treat PDAs in 1966,\(^5\) now delivers a variety of devices for PDA occlusion.\(^6-9\) Few have studied these devices in comparison with surgical ligation. Although preterm infants are too small for the use of transcatheter approaches, controversy remains as to which management option is optimal for the rest of the pediatric population. In this systematic review, we examine all studies with direct comparisons between surgical ligation and transcatheter approaches for PDA closure in nonpremature children.

### Materials and Methods

We followed the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement\(^10\) (e-Appendix 1). The meta-analysis was performed using the methodology suggested by the Meta-analysis of Observational Studies in Epidemiology (MOOSE) group.\(^11\)

We performed a systematic search of all articles from 1950 to February 20, 2014, in MEDLINE, Embase, PubMed, and the Cochrane Central Register of Controlled Trials. Our search strategy included the terms Pediatric OR child* OR neonate* OR infant AND PDA OR patent ductus AND Trans-catheter OR occlusion OR coil* OR clip OR radiologic OR interventional OR device OR surgery OR ligation OR suture including MeSH headings of patent ductus and surgery. The full search strategy can be seen in e-Appendix 2. A hand search of references from included studies was performed to identify additional publications. No language restrictions were placed, and non-English papers were translated. The authors attempted to contact authors to retrieve missing data when necessary to determine whether the article met the inclusion/exclusion criteria or for data abstraction.

Study titles, abstracts, and full articles were reviewed independently by two authors (J. Y. L. and M. E. B.) for inclusion. Disagreements were resolved by consensus. Studies were included if there was a direct comparison between surgical ligation and catheter-based therapies for PDAs in the pediatric population. Studies were excluded if they had fewer than four subjects or if they examined preterm infants or adult patients without a population of nonpremature pediatric patients that could be analyzed separately. Studies were also excluded if they contained duplicate or nonoriginal data, animal subjects, a lack of direct comparison between the interventions, or an absence of clinical outcomes, or if separate/missing data were not available despite attempts to contact authors. All comparative study designs were considered.

The primary outcome of interest was residual or recurrent PDA requiring repeat intervention. Secondary outcome measures included complications, hospital length of stay (LOS), length of procedure, and cost of intervention. We converted reported costs into United States dollars using historical exchange rates.\(^12\) Because the studies spanned a number of years, we used the exchange rate on the median date of data collection.

Two reviewers (J. Y. L. and M. E. B.) independently extracted data using a standardized form (e-Appendix 3). Data collected included publication date, country and institute where the study was performed, dates of data collection, study design, number of cases, intervention type, age of the patients, and size of the PDAs, as well as data on primary and secondary outcomes. Three reviewers (J. Y. L., S. R. L., and M. E. B.) analyzed the design and methodologic quality of included studies using the Newcastle-Ottawa Quality Assessment Scale for cohort studies and the Jadad scale for reporting randomized controlled trials (RCTs) to evaluate for the risk of bias.\(^13,14\)

Agreement in title, abstract, and article inclusion was reported using Cohen’s \(k\) statistic. For outcome measures, ORs of observational studies were pooled for both total complication rates and reintervention rates using a random effects model.

Publication bias was assessed by inspecting for asymmetry in the Begg’s funnel plots and by performing Egger’s test for publication bias. All analyses were performed using Stata 13 (StataCorp LP).

### Results

The electronic search yielded 1,333 articles. After duplicates were removed, 711 studies remained (Fig 1). We excluded 638 papers based on review of titles, and an additional 54 papers on review of abstracts (\(\kappa = 0.86\) and 0.83, respectively). An additional five studies were identified based on a hand search of included study references, resulting in a total of 24 studies. The full texts of these articles were evaluated in detail, and 16 studies were excluded (\(\kappa = 1\)). Eight studies met the inclusion criteria and were included in the analysis (one RCT and seven observational cohort studies), for a total of 1,107 children (Fig 1).\(^15-22\)

Study characteristics are summarized in Table 1. We identified one RCT performed at a single center in Vietnam.\(^22\) In this study, 100 patients were randomized equally to either VATS surgical ligation or catheter-based treatment with either the Amplatzer occluder or flipper coils based on PDA size. In the seven observational cohort studies, 1,007 children were treated for PDA.\(^15-21\)

Of these, 590 children underwent surgical ligation (65 by VATS and 525 by thoracotomy), whereas 417 children were treated with catheter-based therapy (192 with Gianturco coils, 20 with Amplatzer occluders, and 205 with the Rashkind double-umbrella system). Patient age ranged from a few days of age to 18 years. All studies
Figure 1 – Flow diagram of study identification, inclusion, and exclusion. \( \kappa \) agreement between reviewers (J. Y. L. and M. E. B.).

excluded patients with other significant comorbidities/cardiac anomalies.

In the RCT, randomization was completed using shuffled sealed envelopes. No attempt was made at blinding, and all patients were accounted for in follow-up.

Of the observational studies, only one study by Dutta et al.\(^{20}\) had appropriate comparability between interventions, matching patients by age, sex, weight, and PDA diameter. Four studies reported adequate accountability of their patients in follow-up and adequate follow-up strategy using echocardiography to document residual or recurrent PDA,\(^ {18-21}\) whereas five studies had adequate follow-up length.\(^ {17-21}\) The two multicenter studies lost points for drawing patients treated with catheter-based therapy from a different community than that of the surgically treated group (Table 2).\(^ {15,20}\) No studies attempted to control for confounding through regression analyses, although stratification was performed in the study by Dutta et al.\(^ {20}\)

Evidence of publication bias was present in these studies. Asymmetry was apparent in Begg’s funnel plots for both reintervention and total complications. For reintervention, Egger’s test shows significant publication bias for reintervention (0.05) but not for complication rates (0.11).

In the observational studies, two of the 590 patients in the surgical ligation group required reintervention for persistent/recurrent PDA, one originally treated by VATS approach and one by thoracotomy; 32 of the 417 patients in the catheter-based group required reintervention, 20 of the 205 with the Rashkind double-umbrella system (9.8%), and 12 of the 192 with Gianturco coils (6.3%). Two studies reported no reintervention in patients treated with either surgical ligation or catheter-based therapy.\(^ {20,21}\) In a pooled analysis of the observational studies, decreased odds of reintervention was associated with surgical ligation compared with catheter-based therapy for PDA (OR, 0.12; 95% CI, 0.03-0.42; \( P \) = .001). These studies demonstrated low heterogeneity, with an \( F \) of 14.4% (\( P \) = .32) (Fig 2). In the RCT, no patients in the surgical arm required reintervention, compared with three patients in the catheter-based treatment arm.\(^ {22}\)

Complications were defined as any clinically important complication directly related to the procedure itself. Examples for the surgery group included recurrent laryngeal nerve injury, need for chest tube (chylothorax, pneumothorax, or other), and diaphragmatic paralysis. Catheter-based complications included embolization with further complications (beyond reintervention) and vascular injuries. Need for transfusion and infection were reported in both groups.

In the observational studies, complications occurred in 85 of 590 patients in the surgical treatment arm and 44 of 417 patients treated with catheter-based therapy. In pooled analysis, there was a nonsignificant increase in the odds of complications associated with surgical therapy (OR, 2.01; 95% CI, 0.68-5.91; \( P \) = .21). There was moderate heterogeneity in these studies, with an \( F \) of 54.6% (\( P \) = .066) (Fig 3). In the RCT, no complications were seen in either treatment group.\(^ {22}\)

Of the observational studies, six reported LOS.\(^ {15,16,18-21}\) As with the RCT, in the observational studies, surgical patients had a longer LOS (Table 3).

Four of the eight studies reported the procedure time for both interventions. In two studies, the total operative time for surgical ligation exceeded the total procedural time for catheter-based therapy.\(^ {20,22}\) In the other two studies, the opposite was true.\(^ {15,18}\) In both studies in which surgical ligation time exceeded catheter procedural time, surgical ligation was performed using a VATS approach (Table 3).

In seven studies, costs were estimated for both interventions. There was a great deal of variability in the results. Three studies showed increased costs with surgery,\(^ {17,20,21}\) whereas two studies reported greater costs with catheter-based approaches.\(^ {15,22}\) Two studies showed almost no difference in cost between the two interventions (Table 4).\(^ {16,18}\) All studies reported the cost of providing treatment as opposed to prices charged for services.
TABLE 1  | Study Characteristics

<table>
<thead>
<tr>
<th>Study</th>
<th>Dates of Data Collection</th>
<th>Age Range, y</th>
<th>Type of Study</th>
<th>Location of Study</th>
<th>Total No. Patients</th>
<th>Surgery Arm</th>
<th>No. Patients</th>
<th>Surgical Technique</th>
<th>No. Patients</th>
<th>Device Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray et al 15</td>
<td>Jun 1982-Dec 1987</td>
<td>&lt; 19</td>
<td>Cohort</td>
<td>Multicenter*</td>
<td>631</td>
<td>446</td>
<td>Thoracotomy</td>
<td>185</td>
<td>Rashkind double umbrella</td>
<td></td>
</tr>
<tr>
<td>Human et al 16</td>
<td>May 1985-Jul 1991</td>
<td>0.6-16.5</td>
<td>Cohort</td>
<td>IWK Children's Hospital, Halifax, NS, Canada</td>
<td>40</td>
<td>20</td>
<td>Thoracotomy</td>
<td>20</td>
<td>Rashkind double umbrella</td>
<td></td>
</tr>
<tr>
<td>Singh et al 17</td>
<td>Jan 1993-Sept 1995</td>
<td>0.5-9.5</td>
<td>Cohort</td>
<td>Children's Hospital of Michigan, Detroit, MI</td>
<td>46</td>
<td>21</td>
<td>Thoracotomy</td>
<td>25</td>
<td>Gianturco coils</td>
<td></td>
</tr>
<tr>
<td>Hawkins et al 18</td>
<td>Jul 1994-Mar 1996</td>
<td>0.3-15</td>
<td>Cohort</td>
<td>Primary Children's Medical Center, Salt Lake City, UT</td>
<td>40</td>
<td>20</td>
<td>Thoracotomy</td>
<td>20</td>
<td>Gianturco coils</td>
<td></td>
</tr>
<tr>
<td>Jacobs et al 19</td>
<td>Jan 1993-Sept 2002</td>
<td>0.04-16.9</td>
<td>Cohort</td>
<td>All Children's Hospital, St. Petersburg, FL</td>
<td>140</td>
<td>41</td>
<td>VATS with conversion</td>
<td>99</td>
<td>Gianturco coils</td>
<td></td>
</tr>
<tr>
<td>Dutta et al 20</td>
<td>Jan 1998-Feb 2004</td>
<td>Median 2.8</td>
<td>Cohort</td>
<td>Multicenter*</td>
<td>72</td>
<td>24</td>
<td>VATS</td>
<td>48</td>
<td>Gianturco coils</td>
<td></td>
</tr>
<tr>
<td>Lin et al 21</td>
<td>Jan 1997-Dec 2006</td>
<td>0.04-0.24</td>
<td>Cohort</td>
<td>Veteran's General Hospital, Kaohsiung, Taiwan</td>
<td>38</td>
<td>18</td>
<td>Thoracotomy</td>
<td>20</td>
<td>Amplatzer occluder</td>
<td></td>
</tr>
<tr>
<td>Liem et al 22</td>
<td>May 2010-Dec 2011</td>
<td>0.25-3</td>
<td>RCT</td>
<td>National Hospital of Pediatrics, Hanoi, Vietnam</td>
<td>100</td>
<td>50</td>
<td>VATS</td>
<td>50</td>
<td>Amplatzer occluder, Flipper coils</td>
<td></td>
</tr>
</tbody>
</table>

RCT = randomized controlled trial; VATS = video-assisted thoracoscopic surgery.

*Centers include The Hospital for Sick Children, Toronto, ON, Canada; Yale University School of Medicine, New Haven, CT; University of Nebraska Medical Center, Omaha, NE; Children’s Hospital, Boston, MA; Texas Children’s Hospital, Houston, TX; Children’s Hospital of Philadelphia, Philadelphia, PA; University of Minnesota Hospital, Minneapolis, MN; University of Michigan Hospitals, Ann Arbor, MI; IWK Children’s Hospital, Halifax, NS, Canada; Children’s Hospital of Northern California, Oakland, CA; British Columbia Children’s Hospital, Vancouver, BC, Canada; Children’s Hospital, Seattle, WA; University of California-San Francisco Medical Center, San Francisco, CA; UCLA Medical Center, Los Angeles, CA.

*Centers include The Hospital for Sick Children, Toronto, and McMaster Children’s Hospital, Hamilton, ON, Canada.
TABLE 2

Assessment of Methodologic Quality for Cohort Studies Using the Ottawa-Newcastle Scoring System

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection</th>
<th>Outcome</th>
<th>Comparability</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray et al.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Human et al.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Singh et al.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Hawkins et al.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Dutta et al.</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Lin et al.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Overall</td>
<td>(Excluded)</td>
<td>(Excluded)</td>
<td>(Excluded)</td>
<td>(Excluded)</td>
</tr>
</tbody>
</table>

Points for each quality measure given in parentheses, with total reflecting the sum of these points.

Figure 2 – Forest plot of impact of treatment on need for reintervention.

Two of the observational studies examined patients treated with VATS. In total, 65 patients were treated by VATS, with one requiring reintervention; nine of the 147 patients treated with catheter-based therapy required reintervention. Three of the 65 patients treated with VATS had documented complications, compared with one patient in the catheter-based therapy cohort.

Discussion

Surgical ligation of PDA among children and infants of >37 weeks’ gestation resulted in lower rates of reintervention compared with catheter-based techniques. Although each intervention was associated with a different spectrum of complications, surgery had a non-significant tendency toward higher complication rates. Surgery also had a longer LOS, whereas cost and procedural times were variable.

In the single RCT examined, patients in the surgery arm did not require reintervention, whereas 6% required reintervention in the catheter arm. This reintervention rate is higher than that described in large case series examining the efficacy of the Amplatzer occluder. The higher reintervention rate for catheter-based therapy in the RCT is echoed in the pooled analysis of

Figure 3 – Forest plot of impact of treatment on complications.
TABLE 3  | Length of Stay and Procedural Time

<table>
<thead>
<tr>
<th>Study</th>
<th>Dates of Data Collection</th>
<th>Surgical Technique</th>
<th>Operative Time, Mean, min</th>
<th>Device Type</th>
<th>Procedural Time, Mean, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray et al(^{15})</td>
<td>Jun 1982-Dec 1987</td>
<td>Thoracotomy</td>
<td>5.7</td>
<td>Rashkind double umbrella</td>
<td>2.4</td>
</tr>
<tr>
<td>Human et al(^{16})</td>
<td>May 1985-Jul 1991</td>
<td>Thoracotomy</td>
<td>5.6</td>
<td>Rashkind double umbrella</td>
<td>2</td>
</tr>
<tr>
<td>Singh et al(^{17})</td>
<td>Jan 1993-Sept 1995</td>
<td>Thoracotomy</td>
<td>...</td>
<td>Gianturco coils</td>
<td>...</td>
</tr>
<tr>
<td>Hawkins et al(^{18})</td>
<td>Jul 1994-Mar 1996</td>
<td>Thoracotomy</td>
<td>1.1</td>
<td>Gianturco coils</td>
<td>0.5</td>
</tr>
<tr>
<td>Jacobs et al(^{19})</td>
<td>Jan 1993-Sept 2002</td>
<td>VATS with conversion</td>
<td>1.8</td>
<td>Gianturco coils</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Dutta et al(^{20})</td>
<td>Jan 1998-Feb 2004</td>
<td>VATS</td>
<td>1.6</td>
<td>Gianturco coils</td>
<td>0.6</td>
</tr>
<tr>
<td>Lin et al(^{21})</td>
<td>Jan 1997-Dec 2006</td>
<td>Thoracotomy</td>
<td>14.7</td>
<td>Amplatzer occluder</td>
<td>9</td>
</tr>
<tr>
<td>Liem et al(^{22})</td>
<td>May 2010-Dec 2011</td>
<td>VATS</td>
<td>3.5</td>
<td>Amplatzer occluder, Flipper coils</td>
<td>3</td>
</tr>
</tbody>
</table>

See Table 1 legend for expansion of abbreviations.
### TABLE 4  Comparison of Cost Between Surgical and Catheter-Based Treatment Arms

<table>
<thead>
<tr>
<th>Study</th>
<th>Dates of Data Collection</th>
<th>Median Date</th>
<th>Dollar Type</th>
<th>Conversion Rate</th>
<th>Surgical Technique</th>
<th>Cost (Mean) Surgery Arm</th>
<th>Cost (USD) Surgery Arm</th>
<th>Cost (Mean) Catheter Arm</th>
<th>Cost (USD) Catheter Arm</th>
<th>Cost Difference Absolute</th>
<th>Cost Difference Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray et al</td>
<td>Jun 1982-Dec 1987</td>
<td>Mar 15, 1985</td>
<td>USD</td>
<td>1</td>
<td>Thoracotomy</td>
<td>8,838</td>
<td>8,838</td>
<td>11,466</td>
<td>11,466</td>
<td>2,628</td>
<td>0.297</td>
</tr>
<tr>
<td>Human et al</td>
<td>May 1985-Jul 1991</td>
<td>Jun 15, 1988</td>
<td>CAD</td>
<td>0.82</td>
<td>Thoracotomy</td>
<td>4,667</td>
<td>3,827</td>
<td>4,690</td>
<td>2,846</td>
<td>19</td>
<td>0.005</td>
</tr>
<tr>
<td>Singh et al</td>
<td>Jan 1993-Sept 1995</td>
<td>Apr 15, 1994</td>
<td>USD</td>
<td>1</td>
<td>Thoracotomy</td>
<td>9,104</td>
<td>9,104</td>
<td>4,897</td>
<td>4,897</td>
<td>–4,207</td>
<td>–0.462</td>
</tr>
<tr>
<td>Jacobs et al</td>
<td>Jan 1993-Sept 2002</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>VATS with conversion</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>Dutta et al</td>
<td>Jan 1998-Feb 2004</td>
<td>Feb 1, 2001</td>
<td>CAD</td>
<td>0.668</td>
<td>VATS</td>
<td>4,283</td>
<td>2,861</td>
<td>3,958</td>
<td>2,644</td>
<td>–217</td>
<td>–0.076</td>
</tr>
<tr>
<td>Lin et al</td>
<td>Jan 1997-Dec 2006</td>
<td>Jan 1, 2001</td>
<td>NTD</td>
<td>0.03</td>
<td>Thoracotomy</td>
<td>245</td>
<td>7,350</td>
<td>145</td>
<td>4,350</td>
<td>–3,000</td>
<td>–0.408</td>
</tr>
<tr>
<td>Liem et al</td>
<td>May 2010-Dec 2011</td>
<td>Mar 1, 2011</td>
<td>USD</td>
<td>1</td>
<td>VATS</td>
<td>645</td>
<td>645</td>
<td>1,260</td>
<td>1,260</td>
<td>615</td>
<td>0.953</td>
</tr>
</tbody>
</table>

Difference in cost of catheter-based therapy over surgical ligation is expressed in both absolute and relative terms. CAD = Canadian dollars; NTD = New Taiwanese dollars; USD = US dollars. See Table 1 for expansion of other abbreviations.
adult and pediatric patients have demonstrated similar inconsistencies.\textsuperscript{34,35}

As with all meta-analyses, the quality of pooled results is dependent on the quality of the data. A major limitation of this review is the lack of RCTs in the literature. As anticipated, in the observational studies, there was significant selection bias. Only one study had matched cohorts based on patient age, sex, weight, and duct size. The treatment arms of other studies were determined by patient and surgeon preference. In general, studies reported that younger patients and patients with larger or morphologically difficult PDAs were preferentially placed in the surgical arm as opposed to the catheter-based arm. Furthermore, the largest study in the meta-analysis excluded foreign nationals and patients with large ducts at the time of catheterization/operation.\textsuperscript{15} Even excluding these patients, the loss to follow-up was 30%.

In addition, pooled studies vary in the types of surgical therapies and catheter-based therapies. Patients treated with VATS were combined with those treated by thoracotomy, and the various types of catheter-based therapies were combined. Thus, if a particular approach within one of these categories is significantly more or less superior, this will not be apparent in our results. For the primary outcome of need for reintervention, study heterogeneity was low, but for complication rates, there was moderate heterogeneity, limiting the interpretation of the results.

Because the data in these studies span >20 years, the results reflect, to some extent, the outcomes of historical devices and approaches. Only 20 of the 417 patients in the catheter-based treatment arm of the observational studies were treated with the Amplatzer occluder, the device used most worldwide.\textsuperscript{24,27,36,37} A study by Ghasemi et al\textsuperscript{9} compared patients who had catheter-based occlusion of their PDAs with patients treated with a variety of devices, including Gianturco coils, flipper coils, the Amplatzer occluder, and Nit Occlud coils. Patients treated by Gianturco and flipper coils had increased residual shunting compared with those treated with either the Amplatzer occluder or the Nit Occlud coils. There were no mortalities, and major complications ranged from 10.9% (Gianturco coils) to 0.7% (Amplatzer occluder). An additional study of children with PDAs occluded with either the Amplatzer occluder or flipper coils had no mortality and low morbidity rates in both groups; however, the Amplatzer group had fewer reinterventions.\textsuperscript{6}

Conclusions

Closure of the nonpremature pediatric PDA using surgical therapies is associated with lower reintervention rates. Whether this comes at a cost of greater complications is unclear. This meta-analysis did not include premature infants and, thus, the results should not be generalized to this patient population. VATS for occlusion of PDAs presents an attractive alternative to open surgical ligation in the appropriately selected patient. However, few studies have compared VATS with catheter-based therapies, specifically the Amplatzer occluder. With the evolution of surgical and catheter-based techniques, more large-scale, randomized studies must be carried out comparing VATS to catheter-based therapy using the Amplatzer occluder and other new devices. Studies should further elucidate the optimal treatment strategy for occluding PDAs in specific patient populations based on age, size, and the morphology of the PDA.
Acknowledgments

Author contributions: M. E. B. had access to all the data in this study and takes full responsibility for the integrity of the work. M. E. B. contributed to the conceptualization of the study, the search for candidate studies, and the interpretation of the data; J. Y. L. and M. E. B. contributed to the title, abstract, and full paper review and data abstraction; J. Y. L., S. R. L., and M. E. B. contributed to the quality assessment; F. D. contributed to guidance regarding the context of the study; I. W. Y. M. contributed to the data analysis; J. Y. L. contributed to the drafting of the initial manuscript; and S. R. L., I. W. Y. M., F. D., and M. E. B. contributed to the manuscript revision.

Financial/nonfinancial disclosures: The authors have reported to CHEST that no potential conflicts of interest exist with any companies/organizations whose products or services may be discussed in this article.

Additional information: The e-Appendixes can be found in the Supplemental Materials section of the online article.

References


