9-1-2015

Treatment options for pediatric patent ductus arteriosus: Systematic review and meta-analysis

Jennifer Y. Lam
University of Calgary, jennifer.lam@lhsc.on.ca

Steven R. Lopushinsky
University of Calgary

Irene W.Y. Ma
University of Calgary

Frank Dicke
University of Calgary

Mary E. Brindle
University of Calgary

CHEST

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.

CHEST 2015; 148(3):784-793

Manuscript received December 2, 2014; revision accepted March 16, 2015; originally published Online First April 2, 2015.

ABBREVIATIONS: LOS = length of stay; PDA = patent ductus arteriosus; RCT = randomized controlled trial; VATS = video-assisted thoracoscopic surgery

AFFILIATIONS: From the Department of Surgery (Drs Lam, Lopushinsky, and Brindle), Division of Pediatric General Surgery (Drs Lopushinsky and Brindle), Division of General Internal Medicine (Dr Ma), Department of Medicine, and the Division of Cardiology (Dr Dicke), Department of Pediatrics, University of Calgary, Calgary, AB, Canada.

This study was presented at the annual meeting of the Canadian Association of Pediatric Surgeons, September 2014, Montreal, QC, Canada.

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

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 Pediatr* 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 κ 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

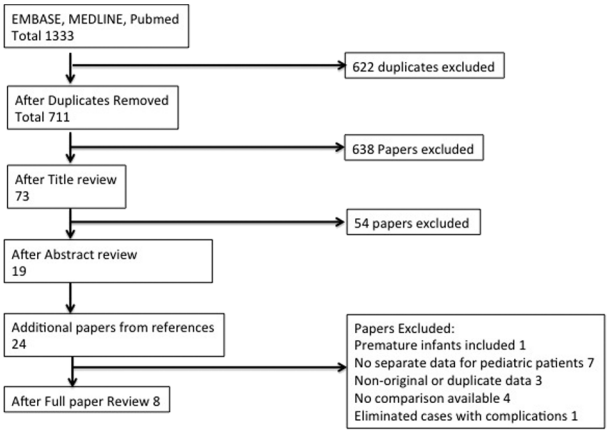

Figure 1 – *Flow diagram of study identification, inclusion, and exclusion.* κ *agreement between reviewers (J. Y. L. and M. E. B.).*

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 I^2 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 I^2 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

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

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

[a]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.

[b]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

Study	Selection				Comparability (Cohorts Comparable) (2)	Outcome		
	Representativeness of Cohort (1)	Selection of Nonexposed Cohort (1)	Ascertainment of Exposure (1)	Outcome Not Present at Start (1)		Assessment (1)	Follow-up Long Enough (1)	Adequate Follow-up (1)	Total (9)
Gray et al[15]	1	0	1	1	0	1	0	0	4
Human et al[16]	1	1	1	1	0	1	0	0	5
Singh et al[17]	1	1	1	1	0	1	1	0	6
Hawkins et al[18]	1	1	1	1	0	1	1	1	7
Jacobs et al[19]	1	1	1	1	0	1	1	1	7
Dutta et al[20]	1	0	1	1	2	1	1	1	8
Lin et al[21]	1	1	1	1	0	1	1	1	7

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

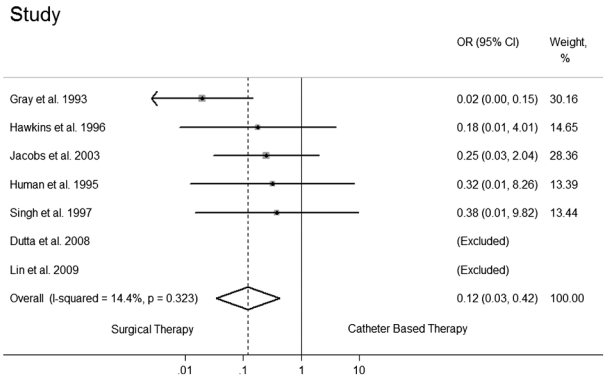

Figure 2 – *Forest plot of impact of treatment on need for reintervention.*

Two of the observational studies examined patients treated with VATS.[19,20] 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 nonsignificant 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.[23-26] The higher reintervention rate for catheter-based therapy in the RCT is echoed in the pooled analysis of

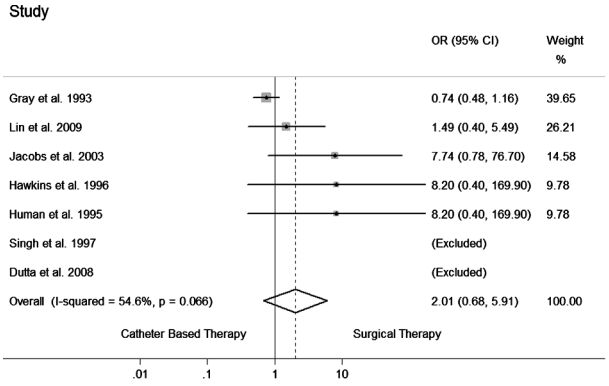

Figure 3 – *Forest plot of impact of treatment on complications.*

TABLE 3] Length of Stay and Procedural Time

Study Characteristics		Surgical Arm			Catheter Arm		
Study	Dates of Data Collection	Surgical Technique	Length of Stay, Mean, d	Operative Time, Mean, min	Device Type	Length of Stay, Mean, d	Procedural Time, Mean, min
Gray et al[15]	Jun 1982-Dec 1987	Thoracotomy	5.7	140	Rashkind double umbrella	2.4	162
Human et al[16]	May 1985-Jul 1991	Thoracotomy	5.6	…	Rashkind double umbrella	2	…
Singh et al[17]	Jan 1993-Sept 1995	Thoracotomy	…	…	Gianturco coils	…	…
Hawkins et al[18]	Jul 1994-Mar 1996	Thoracotomy	1.1	46	Gianturco coils	0.5	101
Jacobs et al[19]	Jan 1993-Sept 2002	VATS with conversion	1.8	…	Gianturco coils	<1	…
Dutta et al[20]	Jan 1998-Feb 2004	VATS	1.6	94	Gianturco coils	0.6	50
Lin et al[21]	Jan 1997-Dec 2006	Thoracotomy	14.7	…	Amplatzer occluder	9	98
Liem et al[22]	May 2010-Dec 2011	VATS	3.5	32	Amplatzer occluder, Flipper coils	3	20

See Table 1 legend for expansion of abbreviations.

observational studies in which surgical therapy had significantly decreased odds of requiring reintervention (pooled OR, 0.12; 95% CI, 0.03-0.42). Complication rates are low for both surgery and interventional approaches to PDAs. No complications were reported in either arm of the RCT, and in the pooled results of observational studies, surgery had an increased risk of complications compared with catheter-based therapies (pooled OR, 2.01; 95% CI, 0.68-5.91). This is a nonsignificant result, but the small numbers leave this finding prone to type 2 error. The studies in our meta-analysis are primarily observational studies with the risks of selection bias and publication biases.

The success of PDA closure via catheter-based intervention is associated with PDA size and morphology.[27,28] Larger PDAs often require more coils or alternative devices; subsequently, it is more difficult to achieve complete closure. Many studies in this review did not include information on the size or morphology of the PDA, nor was consistent information provided in terms of the number of devices used or the decision-making around device selection.

Surgical ligation is more effective in closing PDAs but may be associated with an increased risk of complications. For subjects undergoing the VATS approach, 4.6% had complications, compared with 0.7% of patients treated with catheter-based therapy. The safety and efficacy of VATS is reported in a number of studies.[29-31] In a large case series of pediatric patients with PDA treated by VATS, patients suffered no mortality and low morbidity with 1.3% residual patency.[29] Another study from 2011 compared pediatric patients with PDA treated by either VATS or thoracotomy. No patients required reintervention, but VATS had fewer complications, a lower cost, a shorter LOS, and a shorter time in the operating room.[32] The same authors also compared the outcomes of pediatric and adult PDAs treated either by VATS or by catheter-based therapy using the Amplatzer occluder and found that subjects undergoing VATS did not require reintervention compared with 4.1% in the catheter arm. VATS also had fewer complications and a lower cost but an increased duration of procedure and a longer LOS.[33]

The variability in cost comparisons is likely multifactorial. Costs vary based on treatment location even when controlling for currency. In addition, different studies include different items in their cost analysis. Given these factors, it is difficult to comment on which treatment strategy is more cost effective. Other studies comparing the cost of surgical and catheter-based therapies in

TABLE 4] Comparison of Cost Between Surgical and Catheter-Based Treatment Arms

	Study Characteristics				Surgery Arm			Catheter Arm			Cost Difference	
Study	Dates of Data Collection	Median Date	Dollar Type	Conversion Rate	Surgical Technique	Cost (Mean)	Cost (USD)	Device Type	Cost (Mean)	Cost (USD)	Absolute	Relative
Gray et al[15]	Jun 1982-Dec 1987	Mar 15, 1985	USD	1	Thoracotomy	8,838	8,838	Rashkind double umbrella	11,466	11,466	2,628	0.297
Human et al[16]	May 1985-Jul 1991	Jun 15, 1988	CAD	0.82	Thoracotomy	4,667	3,827	Rashkind double umbrella	4,690	2,846	19	0.005
Singh et al[17]	Jan 1993-Sept 1995	Apr 15, 1994	USD	1	Thoracotomy	9,104	9,104	Gianturco coils	4,897	4,897	−4,207	−0.462
Hawkins et al[18]	Jul 1994-Mar 1996	Apr 15, 1995	USD	1	Thoracotomy	7,101	7,101	Gianturco coils	7,105	7,105	4	0.0006
Jacobs et al[19]	Jan 1993-Sept 2002	…	…	…	VATS with conversion	…	…	Gianturco coils	…	…	…	…
Dutta et al[20]	Jan 1998-Feb 2004	Feb 1, 2001	CAD	0.668	VATS	4,283	2,861	Gianturco coils	3,958	2,644	−217	−0.076
Lin et al[21]	Jan 1997-Dec 2006	Jan 1, 2001	NTD	0.03	Thoracotomy	245	7,350	Amplatzer occluder	145	4,350	−3,000	−0.408
Liem et al[22]	May 2010-Dec 2011	Mar 1, 2011	USD	1	VATS	645	645	Amplatzer occluder, Flipper coils	1,260	1,260	615	0.953

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.[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.[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.[24,27,36,37] A study by Ghasemi et al[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.[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

1. Dice JE, Bhatia J. Patent ductus arteriosus: an overview. *J Pediatr Pharmacol Ther*. 2007;12(3):138-146.
2. Gross RE, Hubbard JP. Surgical ligation of a patent ductus atteriosus. Report of first successful case. *JAMA*. 1939;112(8): 729-731.
3. Mavroudis C, Backer CL, Gevitz M. Forty-six years of patent ductus arteriosus division at Children's Memorial Hospital of Chicago. Standards for comparison. *Ann Surg*. 1994;220(3): 402-410.
4. Labourde F, Noirhomme P, Karam J, Batisse A, Bourel P, Saint Maurice O. A new video assisted thoracoscopic surgical technique for interruption of patient ductus arteriosus in infants and children. *J Thorac Cardiovasc Surg*. 1993;105(2):278-280.
5. Alexi-Meskishvili VV, Böttcher W. The first closure of the persistent ductus arteriosus. *Ann Thorac Surg*. 2010;90(1): 349-356.
6. Sheridan BJ, Ward CJ, Anderson BW, Justo RN. Transcatheter closure of the patent ductus arteriosus: an intention to treat analysis. *Heart Lung Circ*. 2013;22(6):428-432.
7. O'Donnell C, Neutze JM, Skinner JR, Wilson NJ. Transcatheter patent ductus arteriosus occlusion: evolution of techniques and results from the 1990s. *J Paediatr Child Health*. 2001;37(5): 451-455.
8. Brunetti MA, Ringel R, Owada C, et al. Percutaneous closure of patent ductus arteriosus: a multiinstitutional registry comparing multiple devices. *Catheter Cardiovasc Interv*. 2010;76(5):696-702.
9. Ghasemi A, Pandya S, Reddy SV, et al. Trans-catheter closure of patent ductus arteriosus -what is the best device? *Catheter Cardiovasc Interv*. 2010;76(5):687-695.
10. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339:b2535.
11. Stroup DF, Berlin JA, Morton SC, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA*. 2000;283(15):2008-2012.
12. Historical exchange rates. Currency converter website. http://fxtop.com/en/historical-exchange-rates.php. Accessed September 27, 2014.
13. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa Hospital Research Institute website. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed August 14, 2014.
14. Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? *Control Clin Trials*. 1996;17(1):1-12.
15. Gray DT, Fyler DC, Walker AM, Weinstein MC, Chalmers TC; The Patient Ductus Arteriosus Closure Comparative Study Group. Clinical outcomes and costs of transcatheter as compared with surgical closure of patent ductus arteriosus. *N Engl J Med*. 1993;329(21):1517-1523.
16. Human DG, McIntyre L, Gniewek A, Hanna BD. Technology assessment of nonsurgical closure of patent ductus arteriosus: an evaluation of the clinical effectiveness and costs of a new medical device. *Pediatrics*. 1995;96(4 pt 1): 703-706.
17. Singh TP, Morrow WR, Walters HL, Vitale NA, Hakimi M. Coil occlusion versus conventional surgical closure of patent ductus arteriosus. *Am J Cardiol*. 1997;79(9):1283-1285.
18. Hawkins JA, Minich LL, Tani LY, Sturtevant JE, Orsmond GS, McGough EC. Cost and efficacy of surgical ligation versus transcatheter coil occlusion of patent ductus arteriosus. *J Thorac Cardiovasc Surg*. 1996;112(6):1634-1638.
19. Jacobs JP, Giroud JM, Quintessenza JA, et al. The modern approach to patent ductus arteriosus treatment: complementary roles of video-assisted thoracoscopic surgery and interventional cardiology coil occlusion. *Ann Thorac Surg*. 2003; 76(5):1421-1427.
20. Dutta S, Mihailovic A, Benson L, et al. Thoracoscopic ligation versus coil occlusion for patent ductus arteriosus: a matched cohort study of outcomes and cost. *Surg Endosc*. 2008;22(7): 1643-1648.
21. Lin CC, Hsieh KS, Huang TC, Weng KP. Closure of large patent ductus arteriosus in infants. *Am J Cardiol*. 2009;103(6): 857-861.
22. Liem NT, Tung CV, Van Linh N, Tuan TM, Quang H, Tu TT. Outcomes of thoracoscopic clipping versus transcatheter occlusion of patent ductus arteriosus: randomized clinical trial. *J Pediatr Surg*. 2014;49(2):363-366.
23. Behjati-Ardakani M, Behjati-Ardakani MA, Hadadzadeh M, Moshtaghion SH, Sarebanhassanabadi M. Experience with percutaneous closure of ductus arteriosus using the Amplatzer duct occluder in 243 consecutive patients and long-term results - a single centre study. *Niger Med J*. 2014;55(5):394-398.
24. Kang SL, Morgan G, Forsey J, Tometzki A, Martin R. Long-term clinical experience with Amplatzer Ductal Occluder II for closure of the persistent arterial duct in children. *Catheter Cardiovasc Interv*. 2014;83(7):1102-1108.
25. Sungur M, Karakurt C, Ozbarlas N, Baspinar O. Closure of patent ductus arteriosus in children, small infants, and premature babies with Amplatzer duct occluder II additional sizes: multicenter study. *Catheter Cardiovasc Interv*. 2013;82(2):245-252.
26. Baruteau AE, Hascoët S, Baruteau J, et al. Transcatheter closure of patent ductus arteriosus: past, present and future. *Arch Cardiovasc Dis*. 2014;107(2):122-132.
27. Giroud JM, Jacobs JP. Evolution of strategies for management of the patent arterial duct. *Cardiol Young*. 2007;17(suppl 2): 68-74.
28. Fu YC, Hwang B, Jan SL, et al. Influence of ductal size on the results of transcatheter closure of patent ductus arteriosus with coils. *Jpn Heart J*. 2003;44(3): 395-401.
29. Villa E, Folliguet T, Magnano D, Vanden Eynden F, Le Bret E, Laborde F. Video-assisted thoracoscopic clipping of patent ductus arteriosus: close to the gold standard and minimally invasive competitor of percutaneous techniques. *J Cardiovasc Med (Hagerstown)*. 2006;7(3): 210-215.
30. Burke RP, Jacobs JP, Cheng W, Trento A, Fontana GP. Video-assisted thoracoscopic surgery for patent ductus arteriosus in low birth weight neonates and infants. *Pediatrics*. 1999;104(2 pt 1): 227-230.
31. Nezafati MH, Soltani G, Vedadian A. Video-assisted ductal closure with new modifications: minimally invasive, maximally effective, 1,300 cases. *Ann Thorac Surg*. 2007;84(4):1343-1348.
32. Chen H, Weng G, Chen Z, et al. Comparison of posterolateral thoracotomy and video-assisted thoracoscopic clipping for the treatment of patent ductus arteriosus in neonates and infants. *Pediatr Cardiol*. 2011;32(4): 386-390.
33. Chen H, Weng G, Chen Z, et al. Comparison of long-term clinical outcomes and costs between video-assisted thoracoscopic surgery and transcatheter amplatzer occlusion of the patent ductus arteriosus. *Pediatr Cardiol*. 2012;33(2):316-321.
34. Prieto LR, DeCamillo DM, Konrad DJ, Scalet-Longworth L, Latson LA. Comparison of cost and clinical outcome between transcatheter coil occlusion

and surgical closure of isolated patent ductus arteriosus. *Pediatrics*. 1998; 101(6):1020-1024.

35. Fedderly RT, Beekman RH III, Mosca RS, Bove EL, Lloyd TR. Comparison of hospital charges for closure of patent ductus arteriosus by surgery and by transcatheter coil occlusion. *Am J Cardiol*. 1996;77(9):776-779.
36. Faella HJ, Hijazi ZM. Closure of the patent ductus arteriosus with the amplatzer PDA device: immediate results of the international clinical trial. *Catheter Cardiovasc Interv*. 2000;51(1):50-54.
37. Chen ZY, Wu LM, Luo YK, et al. Comparison of long-term clinical outcome between transcatheter Amplatzer occlusion and surgical closure of isolated patent ductus arteriosus. *Chin Med J (Engl)*. 2009;122(10): 1123-1127.