



CONGENITAL HEART SURGERY:

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Association of Pulmonary Conduit Type and Size With Durability in Infants and Young Children

Jeffrey A. Poynter, MD, Pirooz Eghtesady, MD, PhD, Brian W. McCrindle, MD, Henry L. Walters, III, MD, Paul M. Kirshbom, MD, Eugene H. Blackstone, MD, S. Adil Husain, MD, David M. Overman, MD, Erle H. Austin, MD, Tara Karamlou, MD, Andrew J. Lodge, MD, James D. St. Louis, MD, Peter J. Gruber, MD, PhD, Gerhard Ziemer, MD, PhD, Ryan R. Davies, MD, Jeffrey P. Jacobs, MD, John W. Brown, MD, William G. Williams, MD, Christo I. Tchervenkov, MD, Marshall L. Jacobs, MD, and Christopher A. Caldarone, MD,
for the Congenital Heart Surgeons' Society

Divisions of Cardiac Surgery and Pediatric Cardiology, The Hospital for Sick Children, Toronto, Ontario, Canada; Section of Pediatric Cardiothoracic Surgery, Washington University St. Louis, St. Louis, Missouri; Department of Cardiovascular Surgery, Children's Hospital of Michigan, Detroit, Michigan; Division of Cardiac Surgery, Yale University, New Haven, Connecticut; Department of Thoracic and Cardiovascular Surgery, Cleveland Clinic, Cleveland, Ohio; Division of Cardiac Surgery, University of Texas Health Sciences Center, San Antonio, Texas; Division of Cardiovascular Surgery, Children's Hospitals and Clinics of Minnesota, Minneapolis, Minnesota; Division of Cardiac Surgery, Kosair Children's Hospital, Louisville, Kentucky; Division of Cardiac Surgery, University of California San Francisco, San Francisco, California; Division of Cardiovascular Surgery, Duke University, Durham, North Carolina; Division of Cardiothoracic Surgery, University of Minnesota, Minneapolis, Minnesota; Division of Cardiovascular Surgery, Primary Children's Medical Center, Salt Lake City, Utah; Division of Cardiac Surgery, University of Chicago, Chicago, Illinois; Division of Cardiovascular Surgery, Nemours/A.I. DuPont Hospital for Children, Wilmington, Delaware; Division of Cardiac Surgery, Congenital Heart Institute of Florida, St. Petersburg, Florida; Division of Cardiac Surgery, Indiana University School of Medicine, Indianapolis, Indiana; and Division of Cardiovascular Surgery, Montreal Children's Hospital, Montreal, Quebec, Canada

Background. Treatment of congenital heart disease may include placement of a right ventricle to pulmonary artery conduit that requires future surgical replacement. We sought to identify surgeon-modifiable factors associated with durability (defined as freedom from surgical replacement or explantation) of the initial conduit in children less than 2 years of age at initial insertion.

Methods. Since 2002, 429 infants were discharged from 24 Congenital Heart Surgeons' Society member institutions after initial conduit insertion. Parametric hazard analysis identified factors associated with conduit durability while adjusting for patient characteristics, the institution where the conduit was inserted, and time-dependent interval procedures performed after conduit insertion but before replacement/explantation.

Results. In all, 138 conduit replacements (32%) and 3 explantations (1%) were performed. Conduit durability at a median follow-up of 6.0 years (range, 0.1 to 11.7) was 63%. After adjusting for interval procedures and

institution, placement of a conduit with smaller z-score was associated with earlier replacement/explantation ($p = 0.002$). Moreover, conduit durability was substantially reduced with aortic allografts ($p = 0.002$) and pulmonary allografts ($p = 0.03$) compared with bovine jugular venous valved conduits (JVVC). The JVVC were 12 mm to 22 mm in diameter at insertion (compared with 6 mm to 20 mm for allografts); therefore, a parametric propensity-adjusted analysis of patients with aortic or pulmonary allografts versus JVVC with diameter of 12 mm or greater was performed, which verified the superior durability of JVVC.

Conclusions. Pulmonary conduit type and z-score are associated with late conduit durability independent of the effects of institution and subsequent interval procedures. Surgeons can improve long-term conduit durability by judiciously oversizing, and by selecting a JVVC.

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Address correspondence to Dr Caldarone, The Hospital for Sick Children, Division of Cardiac Surgery, University of Toronto, 555 University Ave, Toronto, ON M5G 1X8, Canada; e-mail: christopher.caldarone@sickkids.ca.

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Nearly all valved right ventricle to pulmonary artery (RV-PA) conduits implanted in infants and young children require reinterventions, including explantation or replacement [1]. Although previous reports have compared the durability of conduits according to their type and diameter, a consensus on the optimal conduit for use in infants and young children has not yet been reached. Previous reports are limited by wide age ranges among reported series and because the effects of interval procedures on conduit durability are complex and inconsistently analyzed.

The first analysis of a cohort of children who survived implantation of RV-PA valved conduits in the first 2 years of life and were followed by the Congenital Heart Surgeons' Society (CHSS) Data Center identified risk factors for conduit-related catheter or surgical reintervention and factors associated with progression of conduit dysfunction [1]. Subsequently, Hickey and colleagues [2] compared responsiveness to catheter intervention intended to postpone conduit replacement or explantation, and freedom from conduit-related surgical or catheter intervention in a subset of this cohort limited to children with truncus arteriosus.

In the present analysis, we sought to identify surgeon-modifiable factors that optimize conduit durability in children less than 2 years of age at initial conduit insertion while adjusting for patient characteristics, institution, and subsequent time-dependent interval procedural factors that the surgeon cannot alter during conduit insertion.

Patients and Methods

Between January 1, 2002, and August 8, 2011, 429 children who survived to hospital discharge after insertion of valved RV-PA conduits before 2 years of age were prospectively enrolled from 24 CHSS member institutions (range, 1 to 98 children per institution; see Table E1 in online Appendix). Institutional participation and submission of health information were voluntary and confidential. Parental consent was obtained before enrollment. Ethics Board approval was obtained by the CHSS Data Center and all participating institutions.

Children who received nonvalved conduits, had univentricular morphology, or in whom a ventricular septal defect was intentionally left patent at first conduit insertion were excluded. Table E2 (see online Appendix) lists patient and initial conduit characteristics. Conduit types include nondecellularized aortic allografts (AA [n = 114]) and pulmonary allografts (PA [n = 161]), decellularized aortic allografts (n = 7) and pulmonary allografts (n = 15), bovine jugular venous valved conduits (JVVC [n = 123]), and porcine heterografts (n = 9). Decellularized allografts were considered separately from nondecellularized allografts in all comparisons between conduit types.

Using date of first conduit insertion as time zero, hazard for conduit explanation was modeled using multiphase parametric hazard modeling [3, 4]. We then constructed a model incorporating time-independent variables

(e.g., details of initial conduits) and time-dependent interval procedure variables. Interval procedures were classified as conduit-directed (e.g., conduit stenting), directed near the conduit (e.g., pulmonary artery interventions) or distant from the conduit (namely, directed at the left heart or aorta). Variables incorporated in the model are shown in Table E2 (online Appendix). A unique feature of this method was our consideration of the type and timing of interval procedures as time-dependent covariates.

Differences in available JVVC and allograft sizes (smallest available diameters of 12 mm and 6 mm, respectively) could have resulted in type I error regarding the association of conduit type with late durability. Therefore, a subanalysis was performed to compare propensity-adjusted conduit durability in the subset of children who received JVVC or nondecellularized allografts with diameters of 12 mm or greater, as previously described [2]. (Further methodologic details are provided in the online Appendix.)

Results

Annual cross-sectional follow-up was last performed between July and August 2011 and was complete for 59% in 2011 and 52% in 2010; 106 patients (25%) could not be contacted in either year. At last follow-up, 22 children (5%) were known to have died. Median follow-up was 6.0 years (range, 17 days to 11.7 years).

Of 429 initial conduits, 138 (32%) were explanted and replaced, and 3 (1%) were explanted without replacement. Hereafter, we refer to all of these events as conduit explantations. Interval procedures performed as of last follow-up are listed in Table E3 (online Appendix). Primary indications for conduit explantation included conduit obstruction/stenosis in 97 children, regurgitation in 27, pseudoaneurysm in 8, and unknown in 2. Opportunistic explantation during other surgery is presumed to have occurred for 7 conduits. Indication for first conduit explantation did not differ by conduit type.

Overall Freedom From Conduit Explantation

Time-varying instantaneous risk (hazard) for explantation consisted of an early-peaking hazard at approximately 1 year after insertion together with an underlying constant risk. Overall conduit durability is depicted in Figure 1 (53% at 8 years).

Surgeon-Modifiable Factors Associated With Conduit Explantation

Owing to the low number of explantations associated with the early phase of hazard (n = 16), no risk factors specific to this phase were identified. However, we noted that 12 conduits associated with the early phase were allografts (9 pulmonary, 3 aortic). After designating all important factors not under the surgeon's control as risk adjusters, conduit type (nondecellularized AA and PA in comparison with JVVC) and smaller initial conduit z-score were identified as

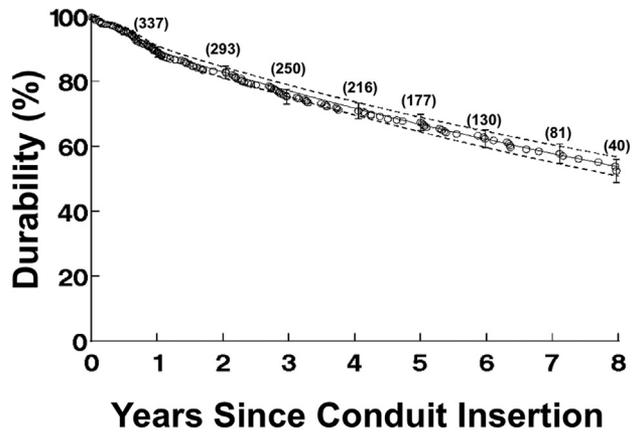


Fig 1. Freedom from explantation (durability) of the initial 429 conduits plotted against time since conduit insertion. Parametrically modeled conduit durability is 53% (70% confidence interval: 49% to 56%) at 8 years after insertion. Each circle represents an explantation; vertical lines are asymmetric confidence limits of 1 SE (68%); numbers in parentheses are children remaining at risk; the solid line is the parametric estimate enclosed in dashed 68% confidence limits.

surgeon-modifiable factors associated with reduced late conduit durability (Table 1).

Figure 2 illustrates that insertion of JVVC rather than allografts and use of larger conduits are both independently associated with increased durability. Durability was independent of other conduit characteristics included

in the model. The numbers of decellularized allografts and porcine heterografts were inadequate to explore any association with durability.

The effect of conduit z-score on durability was explored in a prediction plot generated by solution of the multivariable equation for children with no other risk factors who received AA with z-scores ranging from -1 to +4 (Fig 3). Insertion of an AA with a z-score of +4 instead of -1 was associated with increased 8-year durability from 25% to 59%.

As depicted in Figure 4, JVVC was associated with increased late durability by propensity-adjusted parametric comparison between JVVC and nondecellularized allografts with diameters of 12 mm to 22 mm (n = 279; p < 0.01). This subanalysis further supports our observation that JVVC likely has superior durability independent of conduit z-score in conduits with diameters of 12 mm or greater.

Factors Not Modifiable by Surgeons

Factors that were associated with reduced durability that were not modifiable by the surgeon at conduit insertion include a preoperative diagnosis of aortic stenosis, concomitant repair of truncus arteriosus or double-outlet right ventricle, right pulmonary artery patch arterioplasty, a greater cumulative number of interval conduit stent procedures and a greater number of interval catheter interventions adjacent to the conduit, the occurrence of one or more interval nonconduit operations at any location, and any interval operation at locations distant

Table 1. Risk Factors for Conduit Replacement or Explant

Factor	Original Model			Original Minus Cath Interventions	
	Parameter Estimate	p Value	Bootstrap Reliability (%)	Parameter Estimate	p Value
Factors modifiable by surgeons					
Smaller conduit z-score	0.19	<0.01	65	0.22	<0.01
Conduit type			96		
Aortic allograft	0.76	<0.001		0.72	0.001
Pulmonary allograft	0.60	0.02		0.55	0.02
Factors not modifiable by surgeons					
Preinsertion diagnosis of aortic stenosis	0.77	<0.05	92	0.68	0.08
Truncus arteriosus repair at insertion	0.93	<0.001	81	0.89	<0.001
Double-outlet right ventricle repair at insertion	0.71	<0.05	81	0.64	0.09
Right PA patch arterioplasty at insertion	0.63	0.02	59	0.70	0.002
Institutions					
Institution A	1.62	0.002		1.58	0.003
Institution B	1.10	<0.05		0.97	0.7
Institution C	0.81	<0.01		0.72	0.054
Cumulative no. conduit stent procedures	0.33	<0.01	91	NA	NA
Cumulative no. catheter interventions near conduit	0.16	<0.01	98	NA	NA
One or more nonconduit surgeries at any location	1.89	0.01	79	2.04	<0.01
One or more interval operations distant from conduit	-1.77	0.03	72	-1.87	<0.01

Cath = catheter; NA = not applicable; no. = number; PA = pulmonary artery.

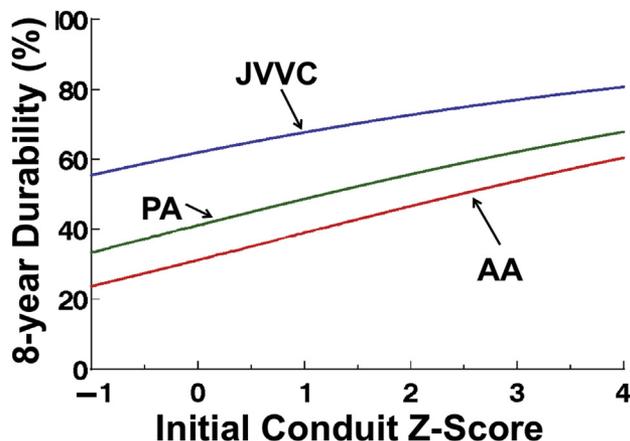


Fig 2. Durability at 8 years after insertion versus conduit z-score. Durability of bovine jugular venous valved conduits (JVVC) is superior to that of nondecellularized pulmonary allografts (PA [$p = 0.02$]) and aortic allografts (AA [$p < 0.001$]) across the full range of conduit z-scores. Larger indexed conduit size is associated with improved durability, regardless of conduit type.

from the conduit (Table 1). We also identified three institutions (accounting for 13, 14, and 70 children) associated with reduced conduit durability despite lack of association with other explanatory variables. In children with a preinsertion diagnosis of aortic stenosis, JVVC were inserted less frequently than nondecellularized allografts (84% allografts versus 12% JVVC; $p < 0.001$). Children requiring concomitant patch arterioplasty of right pulmonary artery stenosis were more likely to have a diagnosis of tetralogy of Fallot ($p = 0.002$).

The cumulative number of interval catheter interventions to stent the initial conduit was associated with reduced conduit durability ($p < 0.0001$). Figure 5 shows the solution to the multivariable parametric equation

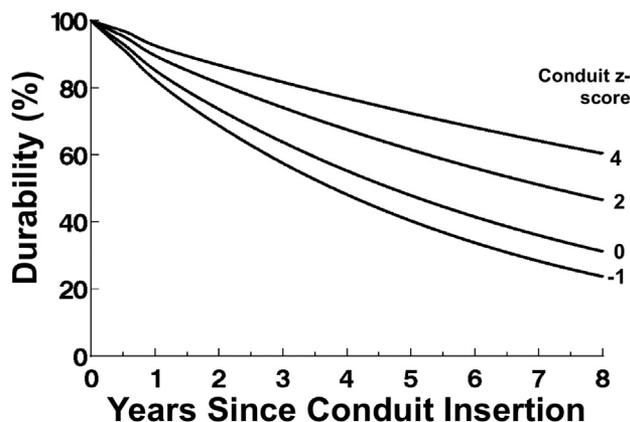


Fig 3. Prediction plot depicting durability for a child who received an aortic allograft with z-scores ranging from -1 to +4 (shown to the right of each line). Without altering other factors, oversizing with a large conduit (z-score +4) instead of inserting a small-for-size conduit (z-score -1) improves 8-year durability from 25% to 59% (assuming the child can accommodate both sizes).

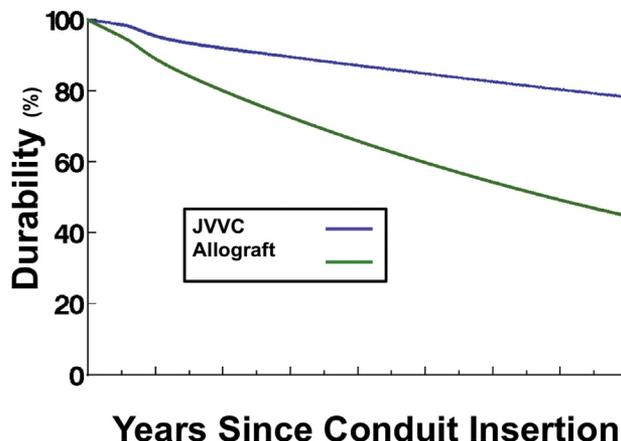


Fig 4. Prediction plot comparing propensity-adjusted durability of bovine jugular venous valved conduits (JVVC [blue]) and nondecellularized aortic or pulmonary allografts (green) with a z-score of 0 inserted into children without other risk factors. The prediction plot is limited to JVVC or allografts of diameter 12 mm or more ($n = 279$) to eliminate selection bias due to a smaller minimum diameter for allografts (6 mm) than for JVVC (12 mm). The JVVC exhibit greater durability at 8 years after insertion ($p < 0.01$).

to predict the durability of an AA with a z-score of +2 inserted into a child without other risk factors who underwent two subsequent catheter interventions to stent the conduit. Each stent deployment was associated with an 18% reduction in 8-year durability when compared with another otherwise identical patient who did not undergo conduit stenting. The associated increase in explanation risk after conduit stenting is similar among

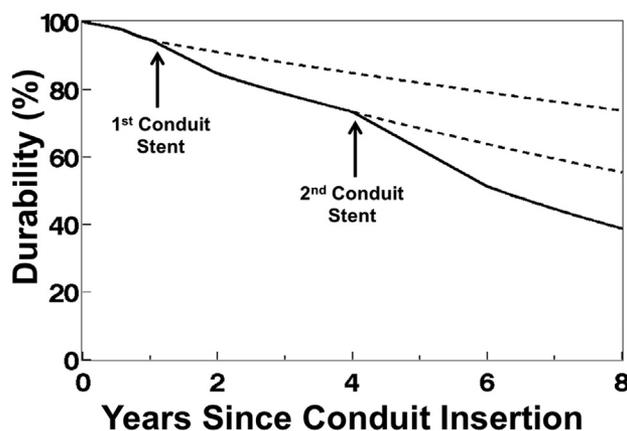


Fig 5. Solution of the parametric equation illustrating the durability of a nondecellularized aortic allograft with z-score +2 inserted in a child with no other risk factors, who underwent two successive conduit stentings at 1 year and 4 years after insertion. The solid line depicts predicted durability over years since conduit insertion on the x-axis. Dotted lines denote predicted durability in a child who did not undergo the first or second conduit stenting procedures. Each stenting is associated with an approximate 18% reduction in 8-year durability.

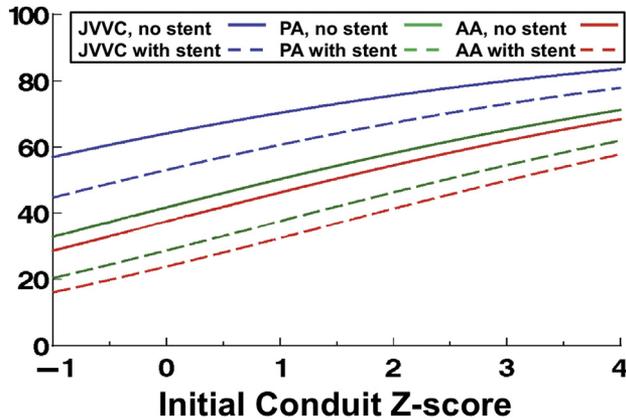


Fig 6. Predicted durability of bovine jugular venous valved conduits (JVVC [blue]), nondecellularized pulmonary allografts (PA [green]), or nondecellularized aortic allografts (AA [red]) inserted into children without other risk factors. Solid lines indicate durability when the conduit did not undergo interval stenting; dashed lines are predicted durability if one interval stenting was performed. Reduction in durability associated with interval stenting is similar among all conduit types ($p = 0.08$).

JVVC, AA, and PA (Fig 6). To test whether interval catheter procedures were responsible for a large portion of the calculated difference in durability by conduit type, we removed interval catheter procedures from our model. When compared, the model parameters produced by this method and those derived when interval procedures were considered in the model are similar (Table 1).

Comment

This multi-institutional prospective observational study found that higher conduit z-score and use of JVVC versus AA and PA were independently associated with greater conduit durability. Statistical methods used in previous analyses did not utilize robust risk adjustment for interval procedures and their subsequent outcomes [1, 2, 5–10]. Furthermore, selection of an endpoint of any catheter or surgical reintervention on the conduit or pulmonary arteries did not permit evaluation of the association of interval procedures with conduit explantation. By using a rigorous methodology to adjust for the type and timing of other factors outside of the surgeon’s immediate control, the present study offers novel insights which have been difficult to support in prior publications.

Surgeon-Modifiable Factors

The estimated benefit of large-diameter conduits noted from our analysis is preserved to the upper limit of our data (a z-score of +5.2). However, the patient-specific constraints of the thoracic space and central pulmonary artery diameter must also be considered. Conduit obstruction represents a common mechanism for conduit explantation in our study and others [1, 10, 11]. Many cases of obstruction may represent stenoses of the

proximal or distal anastomoses or valvar degeneration. An additional mechanism for conduit obstruction may occur as a consequence of somatic outgrowth of the patient in relation to the conduit [7, 10]. Alternatively stated, the physical limitations on the diameter of conduit that may be placed into small infants and young children might eventually result in explantation, even if conduits were not subject to functional deterioration over time. Therefore, insertion of the largest conduit possible (within the constraints of our data and patient size) would be expected to postpone explantation prompted by the somatic growth of the patient.

The present study adds to accumulating evidence that JVVC durability is comparable or superior to allografts [2, 5–9, 12–15]. As Fiore and colleagues [7] discussed, there are numerous possible explanations for the superior durability of JVVC. First, glutaraldehyde preservation of JVVC may reduce exposed antigens, which does not occur as a consequence of cryopreservation [16]. Allograft insertion incites a humoral immune reaction consisting of elevated human leukocyte antigen antibodies and fibroblast migration to graft surfaces [17] as well as a cell-mediated response that may contribute to allograft dysfunction [18, 19]. There were not enough decellularized allografts within the cohort to determine whether this treatment process enhances durability. Second, the right ventricle–JVVC anastomosis may be completed without use of a proximal extension and its attendant addition of prosthetic material. Third, JVVC have larger effective orifice areas due to the structure of the venous valve leaflets. Fourth, the JVVC geometry allows the valve to be placed to nearly abut the anastomosis with the pulmonary artery, leaving the non-valved portion of the conduit to occupy the proximal region of the right ventricular outflow tract—with potential for avoidance of sternal compression and valve distortion, which is often most apparent in the proximal right ventricular outflow tract. In allografts, the valve is fixed in the proximal end of the conduit and the surgeon has less flexibility to move the valve distally to avoid proximal sternal compression. This theoretical benefit of JVVC is partially offset by the relatively longer dimension from the base of the leaflets to the top of the commissures, which can make JVVC implantation in small children challenging. Additional discussion of nonmodifiable factors and confounders is located in the online Appendix.

Comparison to Previous CHSS Studies

The first CHSS analysis of this cohort in 2006 by Karamlou and colleagues [1] identified three risk factors for explantation in agreement with our current findings (smaller indexed right pulmonary artery diameter, bilateral pulmonary artery stenoses, and smaller initial conduit z-score). However, the analysis was unable to discern a difference in time to first catheter or surgical reintervention among the conduit types owing to lower statistical power and the use of different endpoints (catheter or surgical reintervention on the conduit or

pulmonary arteries). Karamlou and colleagues [1] also associated initial conduit z-scores of +1 to +3 with slower progression of conduit stenosis, in agreement with other studies [2, 10]. Differences between the present analysis and that of Karamlou and colleagues [1] may be due to larger cohort enrollment in the present analysis, longer follow-up, and importantly, our statistical methodology and different outcome measure that examines all catheter interventions as interval events. The statistical method we have used in this study cannot include longitudinal echocardiographic data regarding progression of conduit dysfunction.

The analysis of this cohort by Hickey and colleagues [2] in 2008 in the subset of children with truncus arteriosus ($n = 107$, median follow-up 3 years) primarily focused on outcomes of progression of conduit stenosis and regurgitation and risk factors for catheter or surgical reoperation on the right ventricular outflow tract, conduit, or pulmonary arteries. A secondary outcome of conduit durability was examined in a propensity-adjusted parametric hazard model, which determined that smaller initial conduit z-score was associated with earlier explantation in the subset of children with truncus arteriosus. Although the report states that conduit z-scores of +1 to +3 are ideal (in agreement with Karamlou and colleagues [1]), no detrimental effect of more aggressive oversizing was identified. Hickey and colleagues [2] also observed that the propensity-adjusted freedom of JVVC from explantation due to in-conduit stenosis was superior to that of allografts ($p = 0.05$).

With more patients and longer follow-up in the present study, we observed a difference in durability among conduit types regardless of the indication for explantation. Moreover, Hickey and colleagues [2] determined that the rate of gradient progression was reduced by catheter intervention in JVVC ($p < 0.001$), but not in allografts ($p = 0.15$). In the present study, the reduction in durability associated with interval conduit stentings was similar for JVVC, AA, and PA. Furthermore, parameter estimates from a model that did not include catheter interventions as risk adjusters were not substantially different from our original parametric model (Table 1). These data suggest that the observed difference in durability of JVVC and allografts may be principally due to intrinsic characteristics of these conduits, rather than differences in function after catheter intervention.

Study Limitations

Certain limitations of this analysis should be noted. The absence of JVVC available in sizes less than 12 mm resulted in a highly skewed distribution of JVVC z-scores. Because JVVC were of larger indexed size, their durability advantage could be mildly inflated, although our propensity-adjusted secondary analysis suggested the magnitude of this effect did not create a false positive result. In addition, there were fewer conduits with either very small or very large z-scores, which reduced the accuracy of our model at either extreme. We truncated Figure 2 by removing 5% of observations at both ends to

offset this effect. Second, the analysis was not intended to identify factors associated with events other than explantation. Moreover, it was unable to determine why certain interval procedures were associated with conduit durability or their efficacy in postponing explantation. Third, the analysis was subject to the limitations of any prospectively gathered observational study. Clinical decision making was at the sole discretion of each patient's caregivers; their intent cannot be inferred from medical records. Most importantly, any factors absent from the analysis that might have influenced surgeon choice of conduit were potential confounders. As such, this analysis demonstrated associations, but those associations were not necessarily causal.

In conclusion, these data from a large multi-institutional cohort with median follow-up of 6 years suggest that for initial RV-PA valved conduits placed in children less than 2 years of age, surgeons can increase durability by implanting larger conduits. In addition, selecting a JVVC rather than an allograft provides better durability at any indexed size.

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DISCUSSION

DR IVAN M. REBEYKA (Edmonton, Alberta, Canada): Thank you, Dr Rich. I have no disclosures. It is a privilege to discuss the Chamberlain paper for congenital heart surgery presented by Dr Poynter and the CHSS. When Andy Wechsler was the Editor of the *Journal*, he would always stress to us on the editorial board the importance of insuring that the validity of the data and the analysis would allow one to formulate a message that one could, in his words, "take to the bank." The rigorous approach to data collection and statistical analysis performed consistently by the CHSS in their studies have epitomized these requirements.

Having said that, the 2006 paper from the CHSS examined a similar cohort of patients and concluded that RV-PA conduit durability was better if one chose a pulmonary allograft with a z-score between +1 and +3. This finding undoubtedly influenced our clinical approach, yet the results of today's presentation appears to refute this conclusion by recommending that we should now use a bovine jugular venous conduit and make it as big as possible. Jeff, how do you explain these seemingly discrepant results?

DR POYNTER: Thank you, Dr Rebeyka. The present analysis that we performed and the one performed by Dr Karamlou in 2006 are fundamentally different: we have nearly three times the number of patients now and twice as much follow-up, and, most importantly, we have selected a different outcome measure.

Dr Karamlou and colleagues' recommendation to use a conduit with a z-score of +1 to +3 was based on an association with a minimization of progression of conduit gradient and regurgitation indices as defined by echocardiography. For the present study, we chose conduit explantation rather than echocardiographic findings as the outcome, and we found a positive association between conduit size and durability up to the limit of our data, which is a +4 z-score. So I would propose that surgeons insert a conduit up to the limit of our data, which would be a +4, and in many cases conduit selection may be limited by other factors such as available thoracic space or the size of the central pulmonary artery.

DR REBEYKA: Jeff, your conclusions appear to imply that a bovine jugular venous conduit is the optimal choice for the right ventricle position in all clinical scenarios. However, one might hesitate to employ this device when high pulmonary artery pressures are anticipated. So my question is whether you

were able to identify any clinical scenarios or diagnoses where the allograft performed better than the bovine conduit?

DR POYNTER: We looked extensively for interactions with the conduit type and various diagnoses. You might expect, for example, that allografts might be more favorable in children with truncus arteriosus, but we found no such interaction between conduit type and patient diagnosis. It is also important to note that we have excluded any patient who received a palliative conduit in which the ventricular septal defect was either left open or fenestrated, so this cohort is not structured to study conduit durability in the setting of pulmonary hypertension.

DR REBEYKA: My final question relates to a personal observation where I had 3 patients present with endocarditis of a bovine jugular venous conduit over the span of several months. I could only ever recall a single patient with allograft endocarditis during my career, which prompted us to review all of our 378 RV-PA conduits from 2000 to 2012. We found a greater than 10-fold increased incidence of endocarditis in the bovine conduit as compared with the allograft, namely, 8.6% versus 0.75%. Furthermore, more than 60% of patients with bovine conduit infection went on to have obstruction and required conduit replacement. We will be presenting these findings next month at the World Congress in Cape Town but felt that they were relevant to this presentation as they have tempered our initial enthusiasm for the bovine conduit. Do you have any comments on this issue?

DR POYNTER: Yes. I think this is a very interesting topic. In our cohort we have not identified a single conduit replacement that was associated with endocarditis as a primary or even secondary indication. There is simply no evidence of endocarditis in the surgical records at all. That said, when we abstract data, we primarily focus on records from catheter or surgical interventions, and imaging data. We do not abstract other medical admissions that do not result in intervention. And so I think it's entirely possible that some of these children may have been previously admitted with endocarditis. Perhaps it was treated medically, initially successfully, but eventually resulted in conduit stenosis, and it could have therefore indirectly precipitated conduit replacement. I can't exclude that possibility.

DR REBEYKA: Congratulations on a wonderful presentation.

DR ADNAN COBANOGLU (Cleveland, OH): What is the role in your experience for the stentless Freestyle prosthesis in this position in the older patients?

DR POYNTER: Thank you, sir. Can you clarify what you mean by "older patients"?

DR COBANOGLU: Older children.

DR POYNTER: For the purposes of this study, we were limited to children less than 2 years of age, and we had very few Freestyle conduits. I couldn't really comment based on our data for the role of those Freestyle conduits in young children.

DR COBANOGLU: Do you use it in adolescents?

DR POYNTER: I don't personally, no. This study can't provide evidence for or against using Freestyle conduits in an adolescent. These data are only meant to apply to very young children who are less than 2 years of age at the time of insertion of the conduit.

DR COBANOGLU: Because there are data now in quite a few centers that the stentless Freestyle prosthesis works pretty good and the results will be probably comparable to the pulmonary and the aortic homografts in older patients. Thank you.

DR POYNTER: Thank you very much.

DR PETROS ANAGNOSTOPOULOS (Madison, WI): Sometimes when you try to put the Contegra in a newborn, you are limited by the length; in other words, the valve has such length where you cannot use it. Is it possible that this could have been a confounding variable? You did analyze the results in patients up to 2 years of age and if the Contegra was used on older patients in the cohort, could this be the reason they fared better?

DR POYNTER: Yes, I suppose it is possible. We tried to minimize this effect by doing the propensity-adjusted

secondary analysis. Recall that the conduits inserted with a diameter of less than 12 mm were all allografts. Those primarily represent conduits inserted in younger children, as you suggest. We did perform a secondary analysis that was limited to the commonly available range of sizes, which would be 12 to 22 mm, and propensity adjusted that to adjust for selection bias. And even in that scenario, if you note from the bar graph, the jugular venous valved conduit sizes were severely skewed to the left at that point, which would greatly disadvantage them relative to the allografts presented. Within that 12 to 22 mm range, the vast majority of conduits were on the smaller end of that spectrum. Even in that scenario, the jugular venous valved conduits still had greater durability. So I believe we have shown that the durability advantage of jugular venous valved conduits is consistent, even in the setting of the young patient. I would also mention that although patient age at insertion is not directly included in our model, it is incorporated indirectly, because we indexed the conduit z-scores to patient size.

DR GOPICHAND MANNAM (Hyderabad, India): A very nice paper. Congratulations. I just wanted to understand whether it is important to find out what is the duration between the time that you diagnose it as a failure of the conduit, as you said with echocardiography, to the time you actually ended up replacing it. Because your endpoint is explantation regardless of the duration of the failure of the conduit. Would that duration be of importance in terms of determining which conduit is better?

DR POYNTER: Yes, it certainly could be important. One of the limitations of this statistical model is that we cannot include longitudinal echocardiographic data as was done in the previous CHSS study by Dr Karamlou and colleagues. With that in mind, at the time of these interval procedures, we do not know the level of dysfunction of these conduits, nor could we at the time of their replacement. However, we are very close to being able to include that longitudinal data and we hope to update this analysis with that information, hopefully resulting in a better estimate of the effect of these interval procedures on prolonging the time to conduit replacement.