Outcomes of Damus–Kaye–Stansel anastomosis at time of cavopulmonary connection in single ventricle patients at risk of developing systemic ventricular outflow tract obstruction†

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Abstract

OBJECTIVES: Children with various single ventricle anomalies are at risk of developing systemic ventricular outflow tract obstruction (SVOTO) following volume unloading with cavopulmonary connection (CPC). We aim to evaluate the value of Damus–Kaye–Stansel (DKS) anastomosis at the time of CPC in eliminating late SVOTO risk.

METHODS: Retrospective review of single ventricle patients who underwent DKS concurrent with CPC between 1997 and 2012 was performed. Clinical, echocardiographic and angiographic outcomes were analysed.

RESULTS: Thirty-six children with single ventricle underwent DKS at the time of Glenn bidirectional CPC (n = 29) or Fontan total CPC (n = 7). The underlying anatomy was double inlet left ventricle (n = 18), double outlet right ventricle (n = 8), unbalanced atroventricular septal defect (n = 4) and other (n = 6). Prior palliation included pulmonary artery band (n = 35), coarctation/arch repair (n = 11) and atrial septectomy (n = 8). Median age at the time of DKS was 8.9 months (range 3.6 months–9.1 years) and the median weight was 6.7 kg (range 5–27 kg). At the time of DKS, 17 patients (47%) had no SVOT gradient and 19 (53%) had SVOT gradient (mean 23.4 ± 18.7 mmHg). Overall survival was 89 and 83% at 1 month and 5 years, respectively. None of the deaths were related to SVOTO or DKS complications. When present, SVOT gradient decreased from 23.4 ± 18.7 mmHg preoperatively to 0 after DKS (P < 0.001). At the last follow-up, none of the patients developed any SVOT gradient; 78% of them had zero or trivial aortic/neoaortic valve regurgitation while 22% had mild regurgitation. None of the patients had evidence of compression of the left pulmonary artery or bronchus. Eighty-one percent of patients have reached or are suitable candidates awaiting final palliative surgery.

CONCLUSIONS: DKS can be safely performed in conjunction with CPC without added mortality risk. It is very effective in mitigating SVOTO risk, with sustainable good semilunar valves function. Our data support an aggressive approach to performing DKS concurrent with CPC in children with single ventricle pathologies at risk of developing SVOTO.

Keywords: Single ventricle • Fontan • Cavopulmonary connection

INTRODUCTION

Multi-stage palliation is the current management strategy for the treatment of children with various single ventricle cardiac malformations. Several single ventricle anomalies have a systemic ventricular outflow tract (SVOT) that traverses through a bulboventricular foramen between the dominant and rudimentary ventricles, or through a ventricular septal defect (VSD), into the aorta that originates from the small ventricle serving as an outlet chamber. Those patients are at risk of developing systemic ventricular outflow tract obstruction (SVOTO) as the result of a reduction in the size of bulboventricular foramen or VSD early or late after volume unloading with cavopulmonary connection (CPC). Moreover, other single ventricle anomalies are associated with the presence of a subaortic conus that might enlarge with time to cause SVOTO [1–5].

The development of SVOTO could result in unfavorable haemodynamic conditions that might have a detrimental effect on the future of patients with single ventricle, with either failure to progress through palliative stages or late malfunction after final palliation [1–5].

Performance of the modified Damus–Kaye–Stansel operation (DKS) is recommended in single ventricle patients with SVOTO as it allows an unobstructed SVOT and alleviates the haemodynamic effects of obstruction. Moreover, pre-emptive performance of
DKS at the time of CPC in patients with anatomical potential for late SVOTO could offer an advantage of preventing the development of SVOTO and its consequent unfavorable haemodynamic effects [2–9].

In the current series, we describe the anatomical characteristics of children with single ventricle who underwent DKS concomitant with CPC at our institution, and report short- and mid-term clinical outcomes with a focus on the evolution of SVOT haemodynamics with time.

PATIENTS AND METHODS

Inclusion criteria

From 1997 to 2012, 36 consecutive children with variable single ventricle pathologies underwent DKS concomitant with CPC at the King Faisal Hospital and Research Center in Riyadh, Saudi Arabia. Patients who had undergone DKS at the time of first-stage palliation prior to CPC were not included. Demographic, clinical, imaging, operative and outcome data were abstracted from patients’ medical records. Approval for this study was obtained from the Research Ethics Board at our institution and requirement for individual consent was waived for this observational study.

Operative details

The usual surgical techniques were utilized for the performance of Glenn bidirectional CPC (BCPC) and extra-cardiac Fontan total CPC (TCPC) and are not detailed in this manuscript. Our current technique for DKS is briefly described. While end-to-side DKS anastomosis was performed in the past, at present, we perform side-to-side double-barrel DKS anastomosis to preserve the shape of the pulmonary sinus and the native aortic sinus of Valsalva [10, 11].

The DKS operation was performed using conventional cardiopulmonary bypass methods with mild to moderate hypothermia (28–34°C). If open distal anastomosis was necessary, brief circulatory arrest under deep hypothermia was usually done, with selective cerebral perfusion occasionally utilized in cases requiring concomitant arch augmentation.

The ascending aorta is transected above the sinotubular junction and the pulmonary artery is transected at the level of the pulmonary artery band. The pulmonary artery band is removed and the resultant stenosis area of the pulmonary artery is excised. Both aorta and main pulmonary artery are dissected proximally to allow adequate mobility. Following that, a V-shape incision is created in the facing walls and then the two vessels are anastomosed with running polypropylene sutures. Care is taken to maintain original semilunar valve and sinus geometry in their native positions to avoid potential valve distortion. Once this common outlet trunk is constructed, distal anastomosis to the distal ascending aorta is performed. Usually, a cut back at the lesser curvature of the arch is necessary to allow size matching between the two anastomosis ends. In the majority of cases, the distal anastomosis can be performed while the cross clamp is in place; however, open anastomosis with brief circulatory arrest is sometimes necessary.

Concomitant surgery was performed in 10 patients including arch reconstruction (n = 3), pulmonary artery augmentation (n = 3), hybrid preparation for future percutaneous Fontan (n = 2), enlargement of bulbo-ventricular foramen (n = 1), atroventricular valve repair (n = 1), bicuspidization of incompetent aortic valve (n = 1) and pacemaker upgrade (n = 1).

Mean cardiopulmonary bypass and ischaemic times were 101 ± 48 and 57 ± 33 min, respectively.

Follow-up

Time-related outcomes were determined from recent office visits at our institution and from direct correspondence with patients’ families. The mean follow-up duration following DKS was 4.2 ± 4.1 years and was 95% complete.

Statistical analysis

Data are presented as means with standard deviation, medians with minimum and maximum and frequencies as appropriate. Unrelated two-group comparisons were done with unpaired, two-tailed t-tests for continuous variables and Fisher’s exact test for categorical data.

Predictors of hospital mortality were examined using multivariable logistic regression analysis. Estimates for long-term survival or freedom from reoperation were made by the Kaplan–Meier method. Differences between survival curves were evaluated with the log-rank statistic. Cox regression was used to examine independent predictors of late outcomes. All analyses were performed using the SPSS software program (version 20; IBM SPSS Institute, Inc., Chicago, IL, USA).

RESULTS

Patient characteristics

Our patient cohort was 36 children with various single ventricle anomalies. The underlying anatomy was double inlet left ventricle with discordant ventriculo-arterial connection (n = 18), double outlet right ventricle (n = 8), unbalanced atroventricular septal defect (n = 4), dextro-transposition of the great arteries with hypoplastic right ventricle (n = 2), corrected transposition of the great arteries with hypoplastic right ventricle (n = 2), mitral atresia with hypoplastic left ventricle (n = 1) and interrupted aortic arch with subaortic obstruction and mitral stenosis (n = 1). Dominant ventricle was of left morphology (n = 22), right morphology (n = 13) or two equally developed ventricles (n = 1). Two patients had bilateral superior vena cava and 1 had interrupted inferior vena cava. All patients had prior palliation including pulmonary artery band (n = 35), aortic coarctation repair and/or arch reconstruction (n = 11) and atrial septectomy (n = 8). In addition, 1 patient underwent a permanent pacemaker insertion for complete heart block in the interval between first palliative surgery and DKS.

DKS was performed concomitantly with BCPC (n = 29) or TCPC (n = 7). At the time of surgery, 17 patients (47%) had no pressure gradient between the dominant ventricle and the aorta and 19 patients (53%) had pressure gradient between the dominant ventricle and the aorta (median 19 mmHg, range 4–80 mmHg). The median age at the time of DKS was 8.9 months (range 3.6 months–9.1 years) and the median weight was 6.7 kg (range 5–27 kg). There were 25 males (69%) and 11 females (31%) (Table 1).
Clinical outcomes

There were 6 deaths between 12 days and 4.6 months following DKS. Those deaths were related to severe atrioventricular valve regurgitation (n = 2), elevated pulmonary vascular resistance (n = 1), severe respiratory syncytial virus infection (n = 1) and sudden arrest likely due to aspiration (n = 1). The degrees of ventricular dysfunction and atrioventricular valve regurgitation in non-survivors were similar to those pre-operatively and did not show deterioration after DKS. None of the patients had evidence of persistent SVOTO, aortic or neo-aortic valve regurgitation or coronary compromise at the time of death, indicating that mortalities were unrelated to SVOTO or DKS complications.

There were no late deaths, and overall survival at 1 month and 5 years were 89 and 83%, respectively (Fig. 1). Five-year survival were 86% following DKS and BCPC, 69% following DKS and TCPC (log-rank P = 0.30) and 100, 88, 53 and 83% for patients with unbalanced atrioventricular septal defect, double inlet left ventricle, double outlet right ventricle and other anomalies, respectively (log-rank P = 0.31).

Multiple demographic, anatomic, hemodynamic and operative variables were entered into regression analysis to determine the factors affecting outcomes. No variables were identified to significantly affect early or late survival, mainly due to small sample size.

As noted earlier, DKS was performed for potentially obstructive SVOT in 17 patients (47%) who had no pressure difference between the dominant ventricle and aorta. In the other 19 patients (53%), there was a measurable pressure difference between the dominant ventricle and aorta. In the latter group, the pressure difference decreased from mean gradient 23.4 ± 18.7 mmHg preoperatively to 0 mmHg on immediate pre-discharge echocardiograms following DKS (P < 0.001). The follow-up studies including angiograms performed in TCPC candidates showed that gradient remained 0 mmHg in all patients (P = 1.0) (Fig. 2). Prior to DKS, 2 patients had mild aortic regurgitation and 1 had mild pulmonary regurgitation. On immediate pre-discharge echocardiograms, 24/30 survivors had zero or trivial regurgitation of one of the two DKS semilunar valves while 6/30 survivors had mild regurgitation of one of the two DKS semilunar valves. The degree of regurgitation was stable with time, and again 24/30 patients had zero or trivial, and 6/30 patients had mild regurgitation on the last follow-up echocardiograms.

Among the 30 survivors, 29 have reached final palliation stage or are good candidates awaiting final palliative surgery including 1 with interrupted inferior vena cava who underwent the Kawashima operation at the time of BCPC and DKS and 1 who underwent taking down of BCPC and biventricular repair. The remaining 1 patient was not deemed a good candidate for TCPC due to elevated pulmonary vascular resistance and atrioventricular valve regurgitation.

Two patients required permanent pacemaker insertion following DKS. One of them who underwent concomitant enlargement of the bulboventricular foramen had immediate heart block while the other patient developed heart block 5 years following BCPC and DKS. Other reoperations following DKS included aorto-pulmonary shunt in 1 patient with elevated pulmonary vascular resistance, and atrioventricular valve repair plus aorto-pulmonary shunt in one patient followed by atrioventricular valve replacement. Both patients expired.

On the last follow-up, none of the survivors had clinical or imaging evidence of compression of the left pulmonary artery or

Table 1: Characteristics of patients undergoing DKS

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 36)</th>
<th>No pre-DKS gradient (n = 19)</th>
<th>Pre-DKS gradient (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male gender</td>
<td>25 (69%)</td>
<td>13 (68%)</td>
<td>12 (71%)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>1.21 ± 1.48</td>
<td>1.03 ± 0.76</td>
<td>1.42 ± 2.05</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>6.3 ± 0.9</td>
<td>6.4 ± 0.9</td>
<td>6.2 ± 1.1</td>
</tr>
<tr>
<td>Dominant ventricle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>22 (61%)</td>
<td>12 (63%)</td>
<td>10 (59%)</td>
</tr>
<tr>
<td>Right</td>
<td>13 (36%)</td>
<td>6 (32%)</td>
<td>7 (41%)</td>
</tr>
<tr>
<td>Two</td>
<td>1 (3%)</td>
<td>1 (5%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Anatomy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double inlet left ventricle</td>
<td>18 (50%)</td>
<td>9 (47%)</td>
<td>9 (53%)</td>
</tr>
<tr>
<td>Double outlet right ventricle</td>
<td>8 (22%)</td>
<td>4 (21%)</td>
<td>4 (24%)</td>
</tr>
<tr>
<td>Unbalanced atrioventricular septal defect</td>
<td>4 (11%)</td>
<td>1 (5%)</td>
<td>3 (18%)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (17%)</td>
<td>5 (26%)</td>
<td>1 (6%)</td>
</tr>
<tr>
<td>Prior palliation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary artery band</td>
<td>35 (97%)</td>
<td>19 (100%)</td>
<td>16 (94%)</td>
</tr>
<tr>
<td>Aortic coarctation /arch repair</td>
<td>11 (31%)</td>
<td>5 (26%)</td>
<td>6 (35%)</td>
</tr>
<tr>
<td>Atrial septectomy</td>
<td>8 (22%)</td>
<td>5 (26%)</td>
<td>3 (18%)</td>
</tr>
</tbody>
</table>

Figure 1: Overall survival following DKS and CPC.
left bronchus and all survivors were in excellent functional status except for 1 patient suffering from protein losing enteropathy.

**DISCUSSION**

Early or late SVOTO in patients undergoing staged palliation for various single ventricle anomalies is a well-recognized complication and might preclude eventual successful completion of palliative surgeries towards Fontan circulation [1–5]. Two subgroups of patients are at the risk of developing SVOTO. The larger group comprises patients in whom the aorta arises from an outlet chamber that is connected to the single ventricle via a bulboventricular foramen or VSD. This group includes patients with double inlet left ventricle or tricuspid atresia associated with ventriculo-arterial discordance. Also included in this group are some infants with double outlet right ventricle and remote VSD that is unsuitable for biventricular repair and those with transposition of the great arteries associated with hypoplastic right ventricle and VSD. The other smaller group of patients at risk of developing SVOTO includes those with developed subaortic conus that might enlarge with time to cause SVOTO, for example patients with double outlet right ventricle and hypoplastic left ventricle or mitral stenosis/atresia [1–5, 8].

All those anomalies are usually associated with excessive pulmonary blood flow (PBF) and require early control of PBF with a pulmonary artery band to prevent the development of pulmonary vascular disease. While the strategy of early pulmonary artery band followed by BCPC and DKS offers several advantages mainly related to avoiding cardiopulmonary bypass and circulatory arrest in neonates, there are several drawbacks of pulmonary artery band related to the difficulty of obtaining adequate pulmonary vascular protection with pulmonary artery band, possibility of pulmonary artery distortion, small risk of distortion of pulmonary valve with subsequent regurgitation, and most importantly, occurrence of ventricular hypertrophy that might accelerate the rate of narrowing of bulboventricular foramen or VSD with subsequent early development of SVOTO and associated elevated end diastolic pressure leading to the possibility of not qualifying to progress towards the final Fontan circulation. On the other hand, a Norwood-type first-stage palliation offers the advantage of eliminating the risk of SVOTO in addition to the ability to address the problem of significant arch hypoplasia. Taking these factors into consideration, several groups have chosen to perform a Norwood-type first-stage palliation, simultaneously addressing arch obstruction and SVOTO [12–14] while other groups continue to employ pulmonary artery band with or without aortic coarctation repair as their first-stage palliative modality with good outcomes [15–17].

Our approach towards those patients depends on the presence of aortic coarctation and arch hypoplasia, size of bulboventricular foramen/VSD and the presence of subaortic obstruction. In our experience, patients with tricuspid atresia and ventriculo-arterial discordance commonly have aortic coarctation with significant arch hypoplasia, small aortic arch and subaortic obstruction that necessitate Norwood-type palliation in the majority of cases. On the other hand, our decision in patients with double inlet left ventricle and ventriculo-arterial discordance is individualized; patients with significant arch hypoplasia, restrictive bulboventricular foramen or subaortic obstruction are considered candidates for Norwood-type palliation while those with discrete aortic coarctation or mild arch hypoplasia, large bulboventricular foramen and no subaortic obstruction are considered candidates for initial pulmonary artery band and aortic coarctation repair.

The immediate and progressive reduction in single ventricle size associated with volume unloading at the time of BCPC has been shown to increase the incidence of obstruction in patients with anatomic substrate for potential SVOTO development [1–5, 8]. Therefore, several groups have advocated the prophylactic DKS at the time of BCPC in those patients to eliminate the risk of late SVOTO events [6–8]. Our current policy is to perform DKS at the time of BCPC in those patients, although our study cohort includes children who underwent DKS at the time of TCPC. Those patients were done in the earlier part of our experience and usually had tightening of pulmonary artery band to allow maintenance of forward PBF at the time of BCPC, a strategy that we currently rarely apply. Of interest, there are reports in the literature of late performance of DKS in patients who previously had transection of the main pulmonary artery at the time of CPC [18]. At our centre, one patient, not part of our current cohort, had undergone transection of the main pulmonary artery at the time of BCPC followed by TCPC and subsequently developed SVOTO 9 years after TCPC with a 45 mmHg gradient across the restricted bulboventricular foramen. That patient underwent reoperation with DKS that successfully alleviated SVOTO with trivial neo-aortic regurgitation on the late follow-up. Again, that would not be our current policy and the late use of the transected pulmonary valve for DKS is often unlikely given the fact that we currently suture the transected pulmonary valve cusps to decrease the risk of thrombus formation. Almost half of the patients in our series had a gradient across the SVOT at the time of DKS while the remaining did not, which is indicative of the fact that DKS was performed because of the potential anatomic risk, thus reflecting our current policy of aggressively performing DKS at the time of BCPC in those single ventricle variants.

Our survival was 89% at 1 month and 83% at 6 months and after. All our mortalities were related to well-established risk factors for death after CPC such as elevated pulmonary vascular resistance, atrioventricular valve regurgitation, single ventricle dysfunction and respiratory syncytial virus infection. Mortality did not seem to be related to complications associated with SVOTO or the DKS procedure. Despite a longer bypass duration with DKS, our results with concomitant CPC and DKS are comparable to those of contemporary patients who required isolated CPC at our institution [19]. Our outcomes might be inferior to those reported from Western centres due to several factors including delayed initial presentation at the time of first-stage palliation and the unavailability of heart transplantation in this age group in our region, all resulting in higher-risk patients who undergo staged palliation despite not being ideal candidates for CPC [19–22].

The mid-term haemodynamic follow-up in our patients following DKS seems favourable. Despite continued progression of native SVOTO due to the restriction of the bulboventricular foramen or hypertrophy of the subaortic conus, the systemic blood flow remained unobstructed across the pulmonary valve component of the reconstructed common trunk and none of our patient cohort developed any pressure gradient between the dominant ventricle and the aorta, signifying the efficacy of DKS in eliminating and preventing obstruction in patients at risk of developing SVOTO. Importantly, the function of the semilunar valves seems to be well preserved, with the majority of patients having zero or trivial regurgitation at the last follow-up after DKS and none of them having more than mild regurgitation of the aortic or neo-aortic valves. Pulmonary valve regurgitation was rarely
present in our patients prior to DKS, indicating that the strategy of pulmonary artery band is associated with minimal risk of distortion of the pulmonary valve in banded pulmonary arteries, obviously provided that it is left in place for short periods until second-stage BCPC. In addition, those favourable outcomes demonstrate the advantage of using the double-barrel DKS technique that is associated with the preservation of great vessels geometry and semilunar valve function [5, 10, 11]. Besides valve distortion, there are concerns that the pulmonary valve and root would dilate after being subjected to long-standing systemic pressure, which could lead to late development of regurgitation. Sub-commisural reduction of the annulus to stabilize the annulus and prevent late dilatation has been suggested but not performed at our institution. We have not assessed late dilatation of this newly constructed outlet trunk after DKS in the current series, and evidently longer follow-up is necessary to assess the soundness of that subject. Similarly, there are reports of the development of the left pulmonary artery or left main bronchus compression by the bulky DKS in the literature; however, we have not observed any clinical or imaging evidence of that complication in our group of patients [5].

Several groups have advocated the enlargement of the bulboventricular foramen or VSD at the time of BCPC or later as an alternative strategy for the management of single ventricle patients with SVOTO [2, 4, 5, 23, 24]. VSD enlargement is associated with many drawbacks related to the necessity of performing a ventriculotomy in many cases, inadequate relief or recurrence of SVOTO, and high incidence of complete heart block necessitating permanent pacemaker implantation [2, 4, 5, 23, 24]. VSD enlargement might be particularly problematic in patients with AVSD as it might interfere with atrophicventricular valve function following enlargement. In our current cohort, 1 patient who had VSD enlargement concomitant with DKS developed immediate heart block requiring a permanent pacemaker, while another developed heart block 5 years after DKS. Our results suggest an advantage of DKS over VSD enlargement with regard to avoidance of heart block or late recurrence of SVOTO. Therefore, our policy is to reserve VSD enlargement to children with pulmonary regurgitation, pulmonary stenosis or atresia, or the occasional patients who develop late SVOTO after CPC with the inability to perform DKS.

SUMMARY

Certain anatomic subtypes of patients with single ventricle variants are at the risk of developing early or late SVOTO during multi-stage palliation. In those patients, DKS can be safely performed in conjunction with CPC without added mortality risk. DKS is very effective in mitigating SVOTO risk with durable good semilunar valves function. The vast majority of patients ultimately successfully complete the final palliation stage validating the haemodynamic advantages of DKS. Our data support an aggressive approach of performing DKS concurrent with BCPC in children with single ventricle anomalies at the risk of developing SVOTO.

Conflict of interest: none declared.

REFERENCES


