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Morbidity in Children and Adolescents Following Surgical Correction of Truncus Arteriosus Communis

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Abstract

Background—Studies of outcome following operative correction of truncus arteriosus communis (TA) have focused on mortality and rates of re-intervention. We sought to investigate the clinical status of children and adolescents with surgically corrected TA.

Methods and Results—A cross-sectional study of subjects with TA was performed. Subjects underwent concurrent genetic testing, electrocardiogram, cardiac magnetic resonance imaging, cardiopulmonary exercise testing, and completed questionnaires assessing health status and health-related quality of life. Review of their medical history provided retrospective information on cardiac re-intervention and utilization of medical care. Twenty-five subjects with a median age of 11.8 (8.1-18.99) years were enrolled. The prevalence of 22q11.2 deletion was 32%. Incidence of hospitalization, cardiac re-intervention, and non-cardiac operations was highest in the first year of life. Combined catheter-based and operative re-intervention rates were 52% on the conduit and 56% on the pulmonary arteries. Right ventricular ejection fraction and end diastolic volume were normal. Moderate or greater truncal valve insufficiency was seen in 11% of subject, and truncal valve replacement occurred in 8% of subjects. Maximal oxygen consumption (p=0002), maximal

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work (p<0.0001), and forced vital capacity (p<0.0001) were all lower than normal for age and sex. Physical health status and health-related quality of life were both severely diminished.

Conclusion—Patients with TA demonstrate significant co-morbid disease throughout childhood, significant burden of operative and catheter-based re-intervention, and deficits in exercise performance, functional status, and health-related quality of life.

Keywords

Truncus arteriosus communis; Cardiac MRI; Cardiopulmonary exercise testing; Quality of life

Background

Truncus arteriosus communis (TA) is defined by a single great vessel from which the pulmonary arteries, aorta, and coronary arteries arise(1). It is a rare lesion, accounting for 0.21-0.34% of congenital heart disease with an incidence of 0.03-0.05 cases per 1000 live births(2). Prior to availability of operative correction, children with TA demonstrated 80% mortality in the first year of life(3). Operative correction(4), has dramatically reduced this risk, and studies have defined the risk of operative and peri-operative mortality and longitudinal risk of re-intervention (specifically for conduit or right ventricular outflow tract obstruction and truncal valve dysfunction) (5-20).

The clinical status of children who have survived operative correction has not been fully assessed Retrospective case series with median follow-up time of 9.4 and 10.5 years, respectively, have reported that 68-98% of subjects are free from heart failure symptoms and exercise intolerance(5,13). To date, no studies of exercise performance, health status, or quality of life have been performed. We sought to provide a multi-dimensional characterization of clinical status in this population.

METHODS

Study Population

The study protocol was approved by the Institutional Review Board of The Children's Hospital of Philadelphia. A cross-sectional study of subjects with surgically corrected TA was performed, combined with retrospective data collection about utilization of healthcare resources. Inclusion criteria were operative correction of TA, age 8 to 18 years. Exclusion criteria included subsequent heart transplant and lack of English fluency, which would prohibit completion of study questionnaires. Subjects were identified through review of clinical and research databases and contacted to obtain consent for study participation. Anatomic classification of TA was performed according to the Van Praagh classification(1).

Data Collection

Subjects underwent comprehensive evaluation at The Children's Hospital of Philadelphia, including review of medical records and interviews with family members to detail cardiac and non-cardiac operative history, medications, review of systems, previous inpatient admissions, and utilization of outpatient specialty medical and surgical services. Study procedures included electrocardiogram (ECG), cardiac MRI (CMR), cardiopulmonary exercise test (CPET), all of which were performed within 3 months of each other. Instruments to assess health status, Child Heath Questionnaire-Parent Form 50 (CHQ50) and health-related quality of life, Parent Child Quality of Life Inventory (PCQLI), were administered by study staff during study visits.

Study procedures were performed as follows. Analysis of 22q11.2DS genotype was performed in all subjects using fluorescence *in situ* hybridization (FISH)(21) or multiplex ligand-dependent probe amplification (MLPA)(22). Electrocardiograms (ECG), cardiac magnetic resonance imaging (CMR), and cardiopulmonary exercise tests (CPET) were performed as described previously(23). For electrocardiograms outcomes of interest included predominant rhythm, heart block, and bundle branch block. For CMR, outcomes of interest were left and right ventricular ejection fraction and cardiac index, right and left ventricular mass, pulmonary/conduit and truncal/neo-aortic valve insufficiency, and RV end-diastolic volume (RVEDV). Normal values were taken from previously published values for children(24,25). Valvar insufficiency was graded as mild <20%, moderate 20-40%, and severe >40%. For CPET, outcomes of interest included oxygen consumption (VO2), maximum work (physical working capacity), vital capacity, and forced vital capacity.

Health status and health-related quality of life were assessed with questionnaires administered during study visits. All subjects and their parents were invited to complete a Parent Child Quality of Life (PCQLI) questionnaire. Parents of subjects were invited to complete a Child Health Questionnaire 50 (CHQ50). For CHQ50 the primary outcome was "transformed physical" and "transformed psychosocial"(26). Health status as assessed by the CHQ50 aims to characterize the level of illness versus wellness in individual subjects and encompasses the impact of physiologic impairment, symptoms, and control over illness on children and has been validated for children across a range of chronic conditions(26). Health related quality of life, as assessed by the PCQLI, quantifies the effect of a specific disease on a subject's ability to function and derive satisfaction from life across a range of contexts. The PCQLI was developed and validated to assess health related quality of life in children with congenital heart disease (27,28). For PCQLI the primary outcome was Total Score, as reported by both subject and parents. Scores from the study population were compared with values of children with "mild congenital heart disease" and "severe congenital heart disease" as previously described(27,29). For CHQ50 sub-domains are also reported as secondary outcomes.

Statistical Analysis

Descriptive statistics for continuous variables were calculated. The analysis was performed in two parts. First, the rate of post-operative hospitalization, re-intervention, and non-cardiac operations were quantified. Since subjects were of different ages at enrollment, risk of events of interest (hospitalizations, cardiac and non-cardiac operations, and catheterizations) were represented as event rates calculated in person-years (number of events divided by the sum of follow-up time for study subjects). Uniformity of event rates was assessed using histograms, and eras were defined based on visual inspection. Event rates were expressed for the entire follow-up period as well as stratified by these eras. Comparisons in incidence rates were made using a chi-square test. Second, subjects' current state was described with CPET, CMR, EKG, health assessment, and health-related quality of life. Student's two tailed t-tests were used to compare the study population to expected values where available. For each domain, primary outcome(s) were defined prior to analysis. No other adjustments were performed to compensate for multiple comparisons. Statistical significance was reached if $p<0.05$. All analyses were performed using Intercooled STATA 9.2 (College Station TX, USA).

RESULTS

Study Population

A total of 99 individuals were identified as potential subjects, of which 33 were not eligible for enrollment (20 were deceased, 7 older than 18 years, 1 underwent heart transplantation, 1 diagnosis of TA was erroneous, and 4 did not receive operative correction of TA, dying in infancy). Of the remaining 66 subjects, 20 could not be contacted, and 16 declined to participate. The 25/66 enrolled subjects represent an enrollment rate of eligible subjects of 38%. Of the enrolled subjects, 64% were female and 100% were white (Table 1). Subjects had a median age of 11.8 (8.1-18.99) years at enrollment in the study. Distribution of presenting anatomy and other patient characteristics at enrollment are summarized in Table 1. A sizable minority (32%) of subjects were diagnosed with 22q11.2 deletion.

Primary Operative Intervention

Single-operation corrections were performed in 96% of subjects, with one subject undergoing pulmonary artery banding followed by operative correction (Table 1). Operations were performed at a median of 14 days of life (inter-quartile range: 5-30 days, range: 1-138 days).

Hospitalizations, Subsequent Catheter-based and Operative Interventions, and Non-Cardiac Operations

The incidence of hospitalizations (for all causes, including cardiac and non-cardiac procedures) was 4.4 per 10 person-years (95% CI: 3.6-5.1 per ten person-years) (Table 2). It was highest in the first year of life, decreasing between 1-8 years ($p<0.001$) and again between 8-18 years ($p<0.001$).

Post-operative cardiac catheterizations were performed at a rate of 1.2 per 10 person-years, of which 0.42 per 10 patient-years involved trans-catheter interventions (Table 2). Rates of cardiac catheterization were higher in the first year of life than ages 1-8 ($p=0.002$), but the rates between ages 1-8 and 8-18 were not significantly different (p=0.090). The rates of interventional catheterization were higher in the first year of life than between ages 1-8 ($p=0.043$) but were not significantly different between ages 1-8 and 8-18 ($p=022$). Cardiac catheterizations were performed in 80% of the cohort (36 catheterizations in 20 subjects), with interventions performed in 36% of the cohort (13 interventions in 9 subjects) (Table 3). The most common intervention was pulmonary artery angioplasty with or without stent, which was performed in 32% of subjects. Conduit angioplasty was performed in 8% of subjects (n=2).

Operative re-intervention rate over the entire follow up period was 0.96 operations per 10 patient-years (Table 2). The rate of cardiac re-operation was higher in the first year of life than ages 1-8 ($p=0.003$), and decreased again between ages 1-8 and 8-18 (p=0.024). Operative re-intervention was performed in more than half of subjects (56%) (23 distinct operations, some of which combined multiple interventions, in 14 subjects). The majority (53%) of operative re-interventions were to replace conduits, which was performed in 12/25 (48%) subjects (Table 3). Truncal valve replacement was performed in 2 subjects (8%). Pulmonary arterioplasty was performed in 24% of subjects. Other operative interventions included tricuspid valvuloplasty (n=2), closure of residual VSD (n=1), and unifocalization of systemic to pulmonary artery collateral (n=1).

Combining trans-catheter and operative interventions, freedom from conduit re-intervention was 52% (both subjects undergoing conduit angioplasty with or without stent eventually underwent conduit replacement) over the study period with follow-up time of 11.75 years

(range: 8.1-18.99 years). The combined rate of re-intervention on conduits was 0.58 interventions per 10 person-years. Freedom from pulmonary artery intervention was 56% (3 of the subjects undergoing pulmonary artery angioplasty with or without stent also underwent operative pulmonary arterioplasty). The total rate (combining operative and trans-catheter interventions) for pulmonary artery intervention was 0.50 interventions per 10 person-years.

Subjects underwent non-cardiac operations at a rate of 0.9 per 10 person-years. The highest rate was in the first year of life, decreasing between 1-8 years and 8-18 years (Table 2, $p<0.001$, $p=0.011$). The most common operations were myringostomy tubes (n=6), palate procedures (n=4), gastrostomy tubes (n=3), and circumcision (n=3). Nissen fundoplication was performed only once.

ECG

ECG were available in 24/25 (96%) of subjects (Table 4). There were no subjects with complete heart block. Bundle branch block was present in 46% of subjects with 10 (42) demonstrating right bundle branch block, 4 (17%) demonstrating partial right bundle branch block, and 1 (4%) demonstrating bi-fascicular block. Subjects were all in sinus or paced rhythm, and no other dysrhythmias were noted. It should be noted that the one pacemaker was placed in this population given second-degree heart block that progressed to complete heart block.

CMR

CMR were available for 92% of subjects (Table 4). CMR measurements demonstrated preserved left ventricular (LV) ejection fraction (64.7±8.0%) and normal indexed LV cardiac index 4.1±1.0 L/min/m^2. Pulmonary or conduit regurgitant fractions were highly variable with a median of 34% (range: 0-47%, inter-quartile range: 5-36%), but with 70% of evaluated subjects demonstrating moderate or greater pulmonary/conduit insufficiency. RVEDV was 92.9±32.9 ml/ m^2, with 30% (7/23) of subjects demonstrating elevated RVEDV (>107 ml/ m^2). RV mass (71.3±19.2 g/m^2) was also significantly larger than LV mass (53.5±19.3 g/m^2, $p=0.0038$). Subjects who had undergone conduit replacement demonstrated smaller conduit regurgitant fraction and RVEDV than those who had not undergone conduit replacement (PI: 14.1±12.7% versus 33.5±10.5% 95%, $p=0.0017$ and RVEDV 74.1±38.4 ml/m^2 versus 107.4±19.1 ml/m^2, $p=0.013$). RV mass did not differ between those who had or had not undergone conduit replacement (69.1±15.0 g/m^2, 74.4+24.7 g/m^2, $p=0.5417$). Neo-aortic or truncal valve insufficiency was variable (median: 4% range: 0-40%, inter-quartile range: 2-7%). Moderate or greater truncal insufficiency was seen in 11% of subjects.

CPET

CPET were performed in 88% of subjects (22/25); 50% achieved a maximal test (defined as a respiratory exchange ratio ≥ 1.1). Percent predicted forced vital capacity was significantly diminished (75.6±16.8% expected for age and sex, $p<0.0001$, 95% CI 67.5-83.7%), while the ratio of forced expiration in one second to forced vital capacity (FEV1/FVC) was normal 0.87±0.08. Oxygen consumption at maximal exertion (mVO2) (75.3±24.3% percent expected for age and sex, n=19, $p<0.0002$, 95% CI: 63.9-86.7%) and maximal work (2.3±0.7 watts/kg, 74±19% percent expected for age and sex, n=14, $p<0.0001$, 95% CI: 63.0-85.0) were both significantly diminished. In the 10 subjects who performed a maximal exercise test, mVO2 was reduced (80.5±12.9%, 95% CI: 71.3-89.7% p=0.001). Oxygen consumption at anaerobic threshold was also reduced (86±22% expected, n=16, $p=0.02$, 95% CI: 74-98%).

Health Status and Health-related Quality of Life

Health status was measured by the CHQ50 questionnaire, which was completed by 98% of subjects' parents. Parent reports of health status measured through the CHQ PF50 demonstrated significant deficits in Transformed Physical functioning score (48.2± 8.9, p=0.0114, 95% CI: 44.4-52.04), but no significant difference in Transformed Psychosocial functioning score (49.3±7.8, p=0.33, 95% CI: 45.9-52.7). There were several sub-scale domains that showed significant deficits: "general health" (p<0.001) and "parental impact-emotional" (p=0.008), while family cohesion (p=0.0066) was significantly higher than historical controls. However, other subscales did not demonstrate a significant difference.

Health-related quality of life was assessed through the PCQLI questionnaire in twenty (80%) of the study subjects and 23 (92%) of subjects' parents. The total subject PCQLI score (65.4±11.7, 95% CI: 59.9-70.9) was significantly worse than previously published scores for subjects with mild congenital heart disease (80.7±14.4, p<0.0001, 95% CI: 78.6-82.7) but was not significantly different for that in published data about subjects following the Fontan operation (68.7±16.2, p=0.38, 95% CI 66.4-71.0). For parent-reported values, the study population total score (64.6±10.9, 95% CI: 59.9-69.3) was lower than the scores from parents of children with mild congenital heart disease (84.3±13.6, p<0.0001, 95% CI: 82.2-86.4) but not significantly different from the parental scores of subjects following Fontan operation (67.7±16.2, p=0.37, 95% CI: 65.4-70.0).

DISCUSSION

Subjects with TA experienced frequent cardiac re-interventions, non-cardiac operations, and other hospitalizations with higher rates earlier in life, especially in infancy. The cohort demonstrated normal biventricular function, but elevated RV volume and RV mass. It also demonstrated significantly diminished CPET performance. Health status measurement of physical function was diminished relative to historical controls, but psychosocial functional status was not significantly diminished. Health-related quality of life was diminished and comparable to that of children with severe heart disease, represented by the Fontan population. These findings collectively represent moderate morbidity and disability. This study is the first and only study to date to characterize the mid- to late- term outcomes in survivors of operative correction of TA.

Previous studies have demonstrated hospital mortality between 5-19%(5,9,11-14,16,18,19) with the largest series from the Society for Thoracic Surgery Congenital Heart Surgery Database demonstrating an unadjusted mortality of 10%(10,14,20). Our study design does not provide peri-operative mortality data, and we cannot comment on how our cohort compares to those in previous studies in this domain.

Operative re-intervention has been assessed in several studies, primarily focused on conduit and truncal valve replacement. For conduit replacement, a number of retrospective case series (with variable follow-up times) report conduit reoperation rates between 40-70%, with rates increasing with increasing follow-up time(5-8,11,13,30). Re-intervention rates on the conduit (53%) in our study sample were similar to those reported in the literature given our mean follow-up time of 12.5 years with a high prevalence (70%) of at least moderate conduit insufficiency. As might be expected, both conduit insufficiency and indexed RVEDV were reduced in subjects in whom conduit revisions had been performed, while indexed RV mass was not. Reported rates of truncal valve replacement at 10 years of follow up range from 5-18%(5,9,13) with one series reporting 18% rate of replacement with 30 years of follow-up(17). In our study population, the rate of truncal valve replacement was only 8%, and only 11% of subjects had more than mild truncal valve insufficiency.

The rate of pulmonary arterial intervention has not been reported previously. In our study catheter-based and operative interventions were performed in 56% of subjects. The distribution of interventions was not uniform. Operative interventions and cardiac catheterizations were most common in the first year of life, with decreasing rates in subsequent years. We conclude that there is an increased early burden of re-intervention for residual or progressive anatomic disease.

In addition to cardiac interventions, utilization of medical care was quantified by incidence of hospitalizations and non-cardiac operations. Hospitalization rate was quite high at a rate of 4.4 per ten person-years, which represents a 44% annual risk of hospitalization for subjects with TA. Both cardiac and non-cardiac interventions occur most in the first year of life with decreasing incidence as subjects aged.

Previously published studies have reported that the majority of subjects are asymptomatic with NYHA class I or II (5,13), but to our knowledge they did not assess their exercise capacity explicitly. CPET has been used as a surrogate for the ability to participate in age appropriate activity. Our cohort demonstrated significant limitations in exercise performance with diminished mVO2 and maximum work. Recognizing that all CPET measurements are effort-dependent and that only 50% of subjects achieved a maximal test (as defined by an RQ≥1.1), a subgroup analysis of subjects with maximal exercise tests was performed with consistent deficits in mVO2. In addition, oxygen consumption at anaerobic threshold was significantly reduced, demonstrating decreased performance at both maximal and submaximal levels of exertion. FVC was significantly reduced, reflecting restrictive lung disease (with normal ratio of FEV1/FVC). We cannot determine if restrictive lung disease is the result of repeat sternotomy for infant cardiac surgery, parenchymal lung disease reducing lung capacity, musculoskeletal disease, or some other factor. Restrictive lung disease has not been previously reported in subjects with TA or 22q11.2 microdeletion. These findings are consistent with findings from our assessment of functional status in which parents report significantly diminished physical function with preserved psychosocial function. This demonstrates clear morbidity in physical function, despite preserved resting ejection fraction and cardiac index.

Questionnaire based assessment of health status and health-related quality of life have not been applied, to our knowledge, to children with TA previously. Our study sample demonstrates significant deficit in physical functioning as reported by the CHQ50 and PCQLI. However, psychosocial functional status was not significantly different from historical controls. At the same time, the PCQLI, which specifically focuses on the effect of cardiac disease on quality of life, was significantly diminished, relative to children with "mild heart disease," and not significantly different than children with "severe heart disease." This suggests that there are deficits in physical and psychosocial quality of life, which are demonstrable on the more sensitive test. In total, the deficits in quality of life and health status are on par with historical controls with "severe heart disease"(27,29). Further investigation into the reasons for these severe deficits in health-related quality of life are necessary.

There are several limitations to this study. Study subjects all survived infant heart surgeries into school age and adolescence. The study population was limited to those who were willing to participate, and therefore subject to selection bias. Given limited information about subjects who declined to participate or were not reachable, no sensitivity analyses or further assessment of selection bias are possible at this time. The study was not powered for any specific outcome, and in several domains, hypothesis testing was performed for multiple endpoints. Primary endpoints were identified, and, therefore, no additional measures were taken to compensate for multiple comparisons. We acknowledge that cross-sectional data is

limited in its ability to demonstrate causality. To test specific hypotheses, further studies are necessary. Finally, our cohort is not of sufficient size to compare the effect of 22q11.2 deletion on other outcomes. It is therefore unclear to what degree the sample is or is not biased by 22q11.2 deleted portion of the cohort. Nonetheless, as this is consistent with previously reported prevalence of 22q11.2 deletion(21,31), this data is representative of the TA population overall.

In presenting multiple aspects of clinical status, these data present a broad picture of the health of children with TA. In an era with increasingly low operative mortality, prognosis should be measured not only by mortality and rate of cardiac re-intervention, but also by the ability to participate in age-appropriate activities, burden of medical care on families, and quality of life. This is especially true when fetal diagnosis provides greater time and opportunity to communicate these risks. Our study population demonstrates surprisingly large deficits in several domains. We hope that our findings will help provide updated expectations, guide pre- and post-natal counseling and planning for children born with TA, and offer opportunities to consider novel interventions to improve long term outcome.

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References

1. Van Praagh R, Van Praagh S. The Anatomy of Common Aorticopulmonary Trunk (Truncus Arteriosus Communis) and Its Embryologic Implications: A Study of 57 Necropsy Cases. Am J Cardiol. 1965; 16:406–25. [PubMed: 5828135]
2. de Siena P, Ghorbel M, Chen Q, Yim D, Caputo M. Common arterial trunk: review of surgical strategies and future research. Expert Rev Cardiovasc Ther. 20119; (12):1527–38. [PubMed: 22103872]
3. Marcelletti C, McGoon DC, Mair DD. The natural history of truncus arteriosus. Circulation. 1976; 54(1):108–11. [PubMed: 1277412]
4. McGoon DC, Rastelli GC, Ongley PA. An operation for the correction of truncus arteriosus. JAMA. 1968; 205(2):69–73. [PubMed: 4872743]
5. Brown JW, Ruzmetov M, Okada Y, Vijay P, Turrentine MW. Truncus arteriosus repair: outcomes, risk factors, reoperation and management. Eur J of Cardio-Thoracic Surg. 2001; 20(2):221–7.
6. Chen JM, Glickstein JS, Davies RR, Mercando ML, Hellenbrand WE, Mosca RS, et al. The effect of repair technique on postoperative right-sided obstruction in patients with truncus arteriosus. J Thorac and Cardiovasc Surg. 2005; 129(3):559–68. [PubMed: 15746739]
7. Ebert PA, Turley K, Stanger P, Hoffman JI, Heymann MA, Rudolph AM. Surgical treatment of truncus arteriosus in the first 6 months of life. Ann Surg. 1984 Oct; 200(4):451–6. [PubMed: 6237622]
8. Hickey EJ, McCrindle BW, Blackstone EH, Yeh T, Pigula F, Clarke D, et al. Jugular venous valved conduit (Contegra) matches allograft performance in infant truncus arteriosus repair. Eur J Cardio-Thoracic Surg. 2008 May; 33(5):890–8.
9. Henaine R, Azarnoush K, Belli E, Capderou A, Roussin R, Planché C, et al. Fate of the truncal valve in truncus arteriosus. Ann Thorac Surg. 2008; 85(1):172–8. [PubMed: 18154803]
10. Jacobs JP, O'Brien SM, Pasquali SK, Jacobs ML, Lacour-Gayet FG, Tchervenkov CI, et al. Variation in outcomes for benchmark operations: an analysis of the Society of Thoracic Surgeons Congenital Heart Surgery Database. Ann Thorac Surg. 2011; 92(6):2184–91. [PubMed: 22115229]

11. Kaza AK, Lim H-G, DiBardino DJ, Bautista-Hernandez V, Robinson J, Allan C, et al. Long-term results of right ventricular outflow tract reconstruction in neonatal cardiac surgery: options and outcomes. J Thorac Cardiovasc Surg. 2009; 138(4):911–6. [PubMed: 19660342]
12. Lacour-Gayet F, Serraf A, Komiya T, Sousa-Uva M, Bruniaux J, Touchot A, et al. Truncus arteriosus repair: influence of techniques of right ventricular outflow tract reconstruction. J Thorac Cardiovasc Surg. 1996; 111(4):849–56. [PubMed: 8614146]
13. Rajasinghe HA, McElhinney DB, Reddy VM, Mora BN, Hanley FL. Long-term follow-up of truncus arteriosus repaired in infancy: a twenty-year experience. J Thorac Cardiovasc Surg. 1997; 113(5):869–78. [PubMed: 9159620]
14. Russell HM, Pasquali SK, Jacobs JP, Jacobs ML, O'Brien SM, Mavroudis C, et al. Outcomes of repair of common arterial trunk with truncal valve surgery: a review of the society of thoracic surgeons congenital heart surgery database. Ann of Thorac Surg. 2012; 93(1):164–9. [PubMed: 22088417]
15. Tlaskal T, Chaloupecky V, Hucin B, Gebauer R, Krupickova S, Reich O, et al. Long-term results after correction of persistent truncus arteriosus in 83 patients. Eur J Cardiothorac Surg. 2010 Jun; 37(6):1278–84. [PubMed: 20137966]
16. Urban AE, Sinzobahamvya N, Brecher AM, Wetter J, Malorny S. Truncus arteriosus: ten-year experience with homograft repair in neonates and infants. Ann Thorac Surg. 1998; 66(6 Suppl):S183–8. [PubMed: 9930445]
17. Vohra HA, Whistance RN, Chia AX, Janusauskas V, Nikolaidis N, Roubelakis A, et al. Long-term follow-up after primary complete repair of common arterial trunk with homograft: a 40-year experience. J Thorac Cardiovasc Surg. 2010; 140(2):325–9. [PubMed: 20427059]
18. Thompson LD, McElhinney DB, Reddy M, PETROSSIAN E, Silverman NH, Hanley FL. Neonatal repair of truncus arteriosus: continuing improvement in outcomes. Ann Thorac Surg. 2001 Aug; 72(2):391–5. [PubMed: 11515872]
19. Curi-Curi P, Cervantes J, Soulé M, Erdmenger J, Calderón-Colmenero J, Ramírez S. Early and midterm results of an alternative procedure to homografts in primary repair of truncus arteriosus communis. Congenital heart disease. 2010; 5(3):262–70. [PubMed: 20576045]
20. Jacobs ML, O'Brien SM, Jacobs JP, Mavroudis C, Lacour-Gayet F, Pasquali SK, et al. An empirically based tool for analyzing morbidity associated with operations for congenital heart disease. J Thorac Cardiovasc Surg. 2012; 145(4):1046–1057. [PubMed: 22835225]
21. Goldmuntz E, Clark BJ, Mitchell LE, Jawad AF, Cuneo BF, Reed L, et al. Frequency of 22q11 deletions in patients with conotruncal defects. J Am Coll Card. 1998 Aug; 32(2):492–8.
22. Vorstman JAS, Jalali GR, Rappaport EF, Hacker AM, Scott C, Emanuel BS. MLPA: a rapid, reliable, and sensitive method for detection and analysis of abnormalities of 22q. Hum Mutat. 2006 Aug; 27(8):814–21. [PubMed: 16791841]
23. O'Byrne ML, Mercer-Rosa L, Ingall E, McBride MG, Paridon S, Goldmuntz E. Habitual Exercise Correlates With Exercise Performance in Patients With Conotruncal Abnormalities. Pediatr Cardiol. 2012 Oct 27; 34(4):853–60. [PubMed: 23104594]
24. Lorenz CH. The Range of Normal Values of Cardiovascular Structures in Infants, Children, and Adolescents Measured by Magnetic Resonance Imaging. Pediatr Cardiol. 2000 Jan 1; 21(1):37–46. [PubMed: 10672613]
25. Buechel E, Kaiser T, Jackson C, Schmitz A, Kellenberger CJ. Normal right- and left ventricular volumes and myocardial mass in children measured by steady state free precession cardiovascular magnetic resonance. J Cardiovasc Magn Reson. 2009; 11(1):19. [PubMed: 19545393]
26. HealthActCHQ. The CHQ Scoring and Interpretation Manual. HealthActCHQ. 2008 May.:1–213.
27. Marino BS, Shera D, Wernovsky G, Tomlinson RS, Aguirre A, Gallagher M, et al. The development of the pediatric cardiac quality of life inventory: a quality of life measure for children and adolescents with heart disease. Qual Life Res. 2008 Mar 18; 17(4):613–26. [PubMed: 18347927]
28. Marino BS, Tomlinson RS, Wernovsky G, Drotar D, Newburger JW, Mahony L, et al. Validation of the pediatric cardiac quality of life inventory. Pediatrics. 2010 Sep; 126(3):498–508. [PubMed: 20805147]

29. Marino BS, Uzark K, Ittenbach R, Drotar D. Evaluation of quality of life in children with heart disease. Prog Ped Car. 2010; 29(2):131–8.

30. Tlaskal T, Vojtovic P, Reich O, Hucin B, Gebauer R, Kucera V. Improved results after the primary repair of interrupted aortic arch: impact of a new management protocol with isolated cerebral perfusion. Eur J Cardiothorac Surg. 2010 Jul; 38(1):52–8. [PubMed: 20207551]

31. Peyvandi S, Lupo PJ, Garbarini J, Woyciechowski S, Edman S, Emanuel BS, et al. 22q11.2 Deletions in Patients with Conotruncal Defects: Data from 1,610 Consecutive Cases. Pediatr Cardiol. 2013 Apr 21.

Table 1

Patient Characteristics

Age (years)	11.8 (range 8.1-18.99)
Gender	
Female	64% (16))
Male	36% (9)
Race	
White	100% (25)
Presenting anatomy:	
TA Type 1	60% (15)
TA Type 2	28% (7)
TA Type 3	8% (2)
TA Type 4	4% (1)
22q11.2 deletion	32% (8)
Weight (kg)	41.9+/-15.3
Height (cm)	145.6 +/-14.7
BMI (kg/sqm)	19.3 +/-4.3
Age at complete repair (days)	14 (range: 1-138, inter-quartile range: 5-30 days)
Surgical Approach	
Single Stage Operation	96% (24)
PA band followed by complete repair	4% (1)
Surgical Repair	
Homograft conduit *	84% (21)
AP window patch and RVOT augmentation	8% (2)
Jatene Procedure	4% (1)
Unknown	4% (1)

Abbreviations: BMI: Body Mass Index, LVOT: left ventricular outflow tract, VSD: ventricular spetal defect

Data are expressed as mean (± SD), median (range and inter-quartile range), or as percentage(number).

* Of the subjects undergoing correction with homograft conduits: several required additional procedures including anastomosis of discontinuous pulmonary arteries (n=2), resection of RV free wall secondary to acute ischemic injury (n=1), ASD closure (n=3), and arch repair for interrupted aortic arch (n=1),

Table 2

Rates of post-operative hospitalization, operation, and cardiac catheterization

	<1 year	**1-8 years**	**8-18 years**	***p*1**	***p*2**
Hospitalizations	20.8 (15.2-26.5)	3.5 (2.7-4.4)	1.8 (1.0-2.6)	<0.001	<0.001
Non-cardiac operations	2.4 (0.5-4.3)	1.0 (0.5-1.4)	0.27 (0.0-0.6)	<0.001	0.011
Cardiac operations	13.2 (8.7-17.7)	0.69 (0.3-1.1)	0.36 (0.0-0.7)	0.003	0.024
Cardiac catheterizations	8.4 (4.8-12.0)	1.7 (1.1-2.3)	1.0 (0.4-1.6)	0.002	0.090
Interventional cardiac Catheterizations	1.6 (0.5-3.6)	0.5 (0.2-1)	0.8 (0.3-1.4)	0.043	0.22

All event rates are expressed as events per 10 person-years and 95% confidence intervals.

1 p-value is for the comparison between event rates <1 year and 1-8 years.

2 p-value is for the comparison between event rates 1-8 years and 8-18 years.

3 Noncardiac operations included: myringostomy tubes (n=6), palate procedures (n=4), gastrostomy tubes (n=3), Nissen fundoplication(n=1), and circumcision (n=3).

Table 3

Cardiovascular Interventions Following Primary Operative Correction

Cardiac operations	
Total Operations	23 operations in 14 subjects (56%)
Specific Operations	
Conduit replacement	16 operations in 12 subjects (48%)
Truncal Valve replacement	3 operations in 2 subjects (4%)
Pulmonary artery plasty	6 operations in 6 subjects (24%)
Other *	3 (12%)
Pacemaker	1 operation (4%)
Catheterization	
Total	36 in 20 subjects (80%)
Intervention	
	13 in 9 subjects (36%)
Specific Interventions:	
Pulmonary angioplasty +/-stent	10 in 8 subjects (32%)
Conduit angioplasty +/-stent	3 in 2 subjects (8%)
Angioplasty of the aortic arch	1 (4%)

* These included tricuspid valvuoplasty (n=2), residual VSD closure (n=1), and aorto-pulmonary collateral unifocalization (n=1).

Table 4

Electrocardigoram, Cardiac Magnetic Resonance, and Cardiopulmonary Exercise Test

		p
ECG (n=24)		
Normal Sinus Rhythm	100% (24)	
Bundle Branch Block % (n)		
None	36% (9)	
RBBB	42% (10)	
Bifascicular Block	4% (1)	
Intraventricular Conduction Delay	17% (4)	
Cardiac Magnetic Resonance (n=23)		
Pulmonary regurgitant fraction (%) (n=20)	34% (range: 0-47%)	
Indexed LV EDV (ml/sqm) (n=23)	98.4 ± 37.6	
Indexed LV SV (ml/sqm) (n=23)	63.0 ± 23.2	
LV ejection fraction (n=23)	64.7 ± 8.0	
Indexed LV Cardiac Index (L/min/sqm) (n=22)	4.1 ± 1.0	
Indexed LV Mass (g/sqm) (n=22)	53.5 ± 19.3	
Indexed RV EDV (ml/sqm) (n=23)	92.9 ± 32.9	
Indexed RV SV (ml/sqm) (n=22)	71.3 ± 19.2	
RV ejection fraction (n=23)	61.6 ± 7.7	
Indexed RV Cardiac Index (L/min/sqm) (n=22)	4.1 ± 1.0	
Indexed RV Mass (n=22)	71.3 ± 19.2	
Cardiopulmonary Exercise Test (n=22)		
Maximal Effort % (n)* (n=20)	50% (10)	
Respiratory exchange ratio (n=20)	1.12 (1.09-1.34)	
Maximum heart rate (n=19)	179 ± 10	
Forced Vital Capacity (L) (n=19)	2.2 ± 0.8	
Predicted Forced Vital Capacity (%)(n=19)	75.6 ± 16.8	<0.0001
FEV1/FVC (n=19)	0.87 ± 0.08	
Maximum Oxygen Consumption (mVO2) (ml/kg/min) (n=20)	29.3 ± 8.9	
Percent predicted mVO2 (n=20)	75.3 ± 24.3	<0.0002
VAT (ml/kg/min) (n=20)	19.2 ± 5.1	
Percent predicted VAT (n=20)	86 ± 22	0.01
Maximum work (watts/kg) (n=17)	2.3 ± 0.7	<0.0001
Percent predicted max work (n=17)	74 ± 19	
Indexed O2 pulse (mlO2/beat/sqm) (n=20)	4.9 ± 1.3	

Abbvreviations: EDV: end-diastolic volume, FEV1/FVC: one-second forced expiratory volume / forced vital capacity, LV: left ventricle, RBBB: right bundle branch block, RV: right ventricle, SV: stroke volume, VAT: oxygen consumption at anaerobic threshold

Data are expressed as mean (± SD), median (range), or percentage (number).

*Maximal effort is defined as RQ ≥ 1.1 at peak exertion