A Retrospective Analysis of the Influence of Ventricular Morphology on the Perioperative Outcomes After Fontan Surgery

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Objectives: **The objectives of this study were to evaluate the effect of ventricular morphology on perioperative outcomes during Fontan surgery.**

Design: **Retrospective cohort study.**

Setting: **Single standing, not-for-profit pediatric hospital.**

Participants: **A total of 72 patients who underwent Fontan surgery using cardiopulmonary bypass without aortic cross-clamp between January 1, 2009 and December 31, 2014.**

Interventions: **None.**

Measurements and Main Results: **The patients were divided into 3 categories depending on their single-ventricle lesions: (1) LV group (n = 20): left dominant and hypoplastic right ventricle; (2) RV group (n = 37): right dominant and hypoplastic left ventricle; and (3) BV group (n = 15): biventricular or indeterminate dominance. Perioperative major adverse events were collected based on the Society of Thoracic Surgeons database. The need for perioperative allogeneic blood transfusions also was determined. The mean age was 3.3 ± 1.7 years and the mean weight was 13.6 ± 4.0 kg. All patients had extracardiac lateral tunnel or conduit Fontan procedures. Sixty-nine of the patients (96%) underwent tracheal extubation in the operating room. Anesthesia, surgery, and CPB times were 326 ± 68, 239 ± 73, and 70 ± 41 minutes, respectively. Eleven patients (15%) required allogeneic blood products intraoperatively, while 30 patients (42%) required allogeneic blood products during the perioperative period. Length of cardiac intensive care unit stay and hospital stay (median [IQR]) were 1 [1,2] and 12 [9,18] days, respectively. There was no mortality and no significant differences between groups in major postoperative complications, anesthetic or surgical variables.**

Conclusions: **No difference in the immediate perioperative outcomes was noted based on ventricular morphology.**

KEY WORDS: Fontan procedure, pediatric anesthesia, cardiac anesthesia, perioperative outcomes, transfusion

FONTAN SURGERY INITIALLY WAS described in 1971 by Fontan and Baudet.[1] Since the first reports of the procedure, which initially included a direct connection between the atrium and main pulmonary artery (PA) for palliation of tricuspid atresia, several surgical modifications have been introduced, as well as its application for other types of congenital heart disease (CHD).[2,3] In general, Fontan surgery is the final step in surgical palliation for patients with a functionally univentricular heart.

Modifications of the surgical technique, improved survival after the Norwood procedure, and the development of the hybrid procedure (bilateral pulmonary artery banding, ductal stenting, and balloon atrial septostomy) have resulted in an increased number of patients progressing through the Fontan pathway.[4,5] There is also increasing heterogeneity in the type of CHD in these patients. In general, single ventricle lesions can be divided into three categories: (1) left dominant and hypoplastic right ventricle (LV group); (2) right dominant and hypoplastic left ventricle (RV group); and (3) biventricular or indeterminate dominance (BV group). Long-term outcome including morbidity, mortality, and exercise capacity has been shown to be inferior in patients with the hypoplastic left-heart syndrome (HLHS) variant (RV group).[6,7] However, there are limited data evaluating the influence of ventricular morphology on the intraoperative course or the immediate perioperative outcome following Fontan surgery. The current study retrospectively evaluated the effect of ventricular morphology on the intraoperative course and immediate postoperative outcomes, including requirements for allogeneic transfusions and major adverse events.

METHODS

This study was approved by the Institutional Review Board of the Nationwide Children's Hospital in Columbus, Ohio. The need for informed consent was waived. This retrospective study included all pediatric patients, less than 18 years of age, presenting for Fontan surgery using cardiopulmonary bypass (CPB) without aortic cross-clamp in the authors' facility over a five-year period (2009-2014). Patient data were obtained from the Cardiology and Cardiac Surgical Databases, anesthesia records, and the hospital electronic medical record. Preoperative data collected included patient characteristics, as well as echocardiogram and cardiac catheterization reports. Intraoperative data collected included the need for intraoperative allogeneic blood transfusion, inotropic support at termination of CPB, the duration of CPB, the operative time, and the feasibility of tracheal extubation in the operating room (OR). Postoperative data included chest tube output, length of cardiac intensive care unit (CTICU) stay, total hospital stay, the need for re-intubation of the trachea, the administration of allogeneic blood products, morbidity, and mortality. Perioperative major adverse events were collected based on the Society of Thoracic Surgeons database including cardiac arrest, neurologic deficits, acute renal failure requiring hemodialysis or peritoneal dialysis,

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1053-0770/2601-0001$36.00/0

http://dx.doi.org/10.1053/j.jvca.2016.07.024

arrhythmias requiring permanent pacemaker, and multiple organ dysfunction.[8] Other adverse events such as temporary use of pacing devices in the immediate postoperative period, pneumothorax, or pleural and pericardial effusions were not specifically included. Acute kidney injury (AKI) was assessed using the pediatric RIFLE score, which defines AKI as an increase of the serum creatinine by a factor of 1.5 from baseline at any time between postoperative days 0 and 7.[9]

Patients were divided into three groups based on their ventricular dominance according to preoperative studies including echocardiogram and cardiac catheterization. As noted above, these three groups included (1) a dominant left ventricle with or without a rudimentary right ventricle (Group LV); (2) a dominant right ventricle with or without left ventricle (Group RV); and (3) the presence of both ventricles (Group BV). Patients with two ventricles in whom the volume of the smaller ventricle was either $>30\%$ of the main ventricle or was $>50\%$ of its predicted normal value were included in BV group.[10]

Anesthetic Management

Eight patients (11%) were admitted the day before surgery for transcatheter electrophysiologic evaluations in the cardiac catheterization suite, while the remaining patients were admitted the day of surgery. All of the patients were held *nil per os* for 8 hours. After the placement of standard American Society of Anesthesiologists' monitors, anesthesia was induced with either the inhalation of sevoflurane ($n = 64$) or the administration of fentanyl and propofol ($n = 8$) through a pre-existing intravenous cannula. After the induction of general anesthesia, additional peripheral intravenous access was obtained as well as endotracheal intubation facilitated by the administration of rocuronium. Following anesthetic induction, an arterial cannula was placed. As indicated, central venous access was achieved either with a percutaneous central venous catheter placed into the internal jugular vein or femoral vein using ultrasound guidance (15%-20%) or the placement of transthoracic lines in the remaining patients. The transthoracic (atrial) lines were placed following the surgical repair, prior to weaning from CPB. Maintenance anesthesia included 10-to-15 μg/kg of fentanyl, a dexmedetomidine infusion at 0.5 μg/kg/h, and either sevoflurane or isoflurane titrated to clinical need.

Acute normovolemic hemodilution (ANH) was performed whereby 10% to 20% of the total circulating blood volume was withdrawn prior to surgical incision.[11,12] The volume removed was based on the preoperative hematocrit and the estimated target hematocrit on CPB. While the usual practice of ANH is to infuse 3 mL/kg of crystalloid for each 1 mL/kg of autologous blood that is removed, the authors' standardized protocol minimizes the intraoperative administration of crystalloid, especially during the pre-CPB period, to limit the impact on hematocrit during CPB.[11] Hemodynamic parameters and cerebral oxygenation using near-infrared spectroscopy (NIRS) were monitored and maintained with bolus doses of vasoactive agents (phenylephrine 1-2 μg/kg and epinephrine 0.1-0.2 μg/kg) and the administration of crystalloid limited during ANH. In the absence of contraindications, patients were evaluated using transesophageal echocardiography during the pre- and post-CPB periods.

CPB circuit sizes were chosen based on the patients' body weight. Retrograde arterial prime and venous antegrade prime were performed at the initiation of CPB. Hemofiltration or zero-balance ultrafiltration during CPB and modified ultrafiltration after the termination of CPB were performed in all patients as per the authors' previously described protocol.[13,14] In the absence of preoperative contraindications for early tracheal extubation (difficult airway) or intraoperative concerns (bleeding, hemodynamic instability), tracheal extubation was performed in the operating room.[15]

The decision for the use of allogeneic blood products was based on the authors' usual practice including a discussion among the anesthesiologist, perfusionist, and the surgeon. While the goal during CPB generally was to ensure a hematocrit greater than 21%, other parameters were monitored and used to determine the need for transfusion. These included a decrease of the cerebral NIRS of more than 20% from baseline, increased lactate concentration, or decreased urine output that did not respond to a change in the mean arterial pressure with an appropriate CPB flow for the patient's weight and temperature. After separation from CPB, the coagulation profile was not assessed routinely, but rather based on the clinical scenario. In the event of non-surgical bleeding, the protocolized blood product management included the administration of apheresed full-volume platelets (10 mL/kg) and cryoprecipitate (CRYO) (1 unit/10 kg). If bleeding persisted after a second round of platelets and CRYO, 10 mL/kg of fresh frozen plasma (FFP) was transfused.

After arrival to CTICU from the OR, the following laboratory parameters were evaluated: complete blood count (CBC), arterial blood gas, lactate concentration, electrolytes, ionized calcium, and coagulation profile. The protocolized transfusion of packed red blood cells (PRBCs) was based on one or a combination of the following: hypotension, metabolic acidosis as demonstrated by increasing lactate and base deficit, or a decrease in cerebral NIRS by more than 10% from baseline that does not respond to crystalloid administration, and significant bleeding with hemodynamic instability. For treatment of coagulopathy, platelets (10 mL/kg), CRYO (1 unit/10 kg), and FFP (10 mL/kg) were administered as needed. If bleeding persisted with chest tube drainage of more than 5 mL/kg/h, additional blood products were administered based on the CBC and coagulation profile. Recombinant factor VIIa was considered when bleeding still persisted after the second round of blood products.

Statistical Analysis

All demographic and perioperative data were compared among the three groups and also between the groups with or without a hypoplastic left ventricle (Group RV versus Groups LV & BV) as has been performed in previous studies.[7,10] Continuous data were described as mean ± SD or median (IQR). Comparisons among groups were performed using t-tests or analysis of variance for continuous data and Fisher's exact tests for categorical data. Analyses were performed using GraphPad Prism 6 (GraphPad Software, Inc); p value <0.05 was considered statistically significant.