

THE FONTAN PATIENT

Definition

The Fontan operation is a generic term for a group of operations that redirect the systemic venous return to the pulmonary arteries without passing through a subpulmonary ventricle.^{1,2}

³ It is usually the final operation for “univentricular heart” conditions described in the relevant Chapter. The classic Fontan consisted of a valved conduit between the right atrium and pulmonary artery. It was subsequently modified to a direct anastomosis of the right atrium to a divided pulmonary artery (Figure 1A). The intracardiac lateral tunnel consists of an end-to-side anastomosis of the superior vena cava to the undivided right pulmonary artery, and a composite intraatrial tunnel that uses the right atrial lateral wall and prosthetic material to channel inferior vena caval flow to the pulmonary artery (Figure 1B). The “extracardiac” variant of the total cavopulmonary connection Fontan consists of directing inferior vena caval flow to the pulmonary artery by means of an external conduit (Figure 1C).^{4,5} An estimated global population of 70 000 patients have undergone the Fontan procedure and are alive today, most of whom are <25 years of age.⁶

Pathophysiology

Fontan is usually offered to patients with single-ventricle physiology, ie a functionally single ventricle or when biventricular repair is not feasible. Thus, nowadays the so-called Fontan physiology consists of staged approaches that eventually end-up in a single functional ventricle that maintains both the systemic and the passive pulmonary circulation. Symptoms develop when the single functional ventricle fails. The 12-year survival after various types of operation is 70-90%.^{1,7} Extracardiac conduit total cavopulmonary connection, and lack of clinical arrhythmia or right heart failure are good prognostic signs, whereas exercise intolerance is not associated with long-term mortality.⁸ Considerable mortality is still observed during the first years of life among patients with single ventricle. Atrioventricular valve failure (moderate or greater regurgitation, or valve operation) after Fontan is a risk factor for adverse outcomes.⁹ In patients with a functionally univentricular heart undergoing the Fontan procedure, RV dominance is the most important risk factor for death but only before biderictetional superior cavopulmonary anastomosis.¹⁰

Clinical Problems

In the current era, 10-, 20-, and 30-year survival after the Fontan operation was 74%, 61%, and 43%, respectively.¹¹ The Fontan Outcomes Network, now part of the Single Ventricle Outcomes Network, represents one of the largest prospective, multicenter clinical registries of individuals with a Fontan circulation, enrolling >1100 patients across the United States and

Canada within its first 2 years. The first 2 years report demonstrated a high prevalence of Fontan-related complications, including age-associated arrhythmias and thromboembolic events, as well as substantial noncardiac comorbidity across the lifespan.¹²

Pulmonary complications are common post-Fontan procedure, including restrictive lung disease, sleep abnormalities, plastic bronchitis, and cyanosis.¹³ Decompensated patients present with classic **right heart failure**. There is a nonpulsatile high JVP (10 cm) with single S2, and a murmur only if subaortic obstruction or significant systemic AV valve regurgitation. **Fontan-associated liver disease** encompasses a spectrum of hepatic abnormalities that are a consequence of the Fontan circulation. End-stage complications can include cirrhosis, with or without portal hypertension, and potential development of hepatocellular carcinoma.¹⁴ Fontan screening for liver disease includes recommendations for at least annual imaging and laboratory evaluation, including **alpha-fetoprotein**.¹⁵ Routine imaging, transient elastography, and serum biomarkers are unable to accurately assess severity of liver fibrosis.¹⁶ Surveillance biopsies have demonstrated that virtually 100% of these patients develop clinically silent fibrosis by adolescence.⁶ Luminal protein loss can manifest as either a break in the integrity of the intestinal mucosa with the development of **protein losing enteropathy** or as a break in the bronchial mucosa with accumulation of proteinaceous material in the airways forming bronchial casts, or **plastic bronchitis**.¹⁷ Oedema and ascites may be seen as a sign of **protein losing enteropathy** that occurs in 5% to 15% of patients following the Fontan operation, and carries a 5-year mortality >10%.¹⁸ Other problems are arrhythmias due to post-op atrial scarring such as **intra-atrial reentrant tachycardia, atrial flutter and fibrillation**. The most frequent of these is intra-atrial reentrant tachycardia particularly seen with atrio-pulmonary connections. With modern techniques its incidence has been reduced to 7%.¹⁹ Catheter ablation is cumbersome due to multiple circuits and should be attempted only at experienced centers. **Sick sinus syndrome and AV block, thromboembolic complications, progressive AV valve deterioration, liver fibrosis and renal dysfunction, venous insufficiency and neurocognitive deficits** may also occur.¹⁷ **Obstruction of the Fontan connection or the pulmonary artery branches** are being dealt with by stent-based transcatheter pulmonary valve implantation. Brain abnormalities and **neurocognitive impairment** are common in people living with a Fontan circulation and appear more prominent in adults. Clinical factors such as longer inpatient days, younger age at Fontan surgery, and longer time since Fontan completion were associated with worse neurocognitive function.²⁰

Prognosis

Among perioperative survivors of the Fontan operation, in addition to age at Fontan, haemodynamic parameters obtained around 1 year after the operation, such as oxygen

saturation, CVP, ejection fraction, and mean arterial pressure, are important for predicting long-term survival. The occurrence of Fontan-associated morbidities during follow-ups, such as advanced heart failure, severe cyanosis, PLE, and new-onset arrhythmias, provides incremental prognostic information to the baseline risk.²¹ Among patients with congenital heart disease, those Patients with single ventricles have the highest risk of early mortality in the ACHD population. Mild ventricular dysfunction and dilatation by cardiac magnetic resonance, NYHA functional class, and history of protein-losing enteropathy/plastic bronchitis are predictors of sudden cardiac events and death.²²

Therapy

Recommendations are presented in Tables 1-3. There is considerable late morbidity and premature death in adults who underwent the Fontan procedure early in life, particularly following aortopulmonary connections, and the onset of SVT may signal the need to assess the Fontan circulation.²³ The Fontan is typically not the final stage of single-ventricle palliation. In Fontan survivors, two thirds of patients require surgical or catheter-based reintervention by 20 years.²⁴ In patients with exercise intolerance, bosentan improves exercise capacity, exercise time and functional class in Fontan patients without serious adverse events or hepatotoxicity.²⁵ In the FUEL trial, udenafil (87.5 mg bd), a long-acting phosphodiesterase type 5 inhibitor, was not associated with an improvement in oxygen consumption at peak exercise but was associated with improvements in multiple measures of exercise performance at the ventilatory anaerobic threshold.²⁶

Pregnancy

Pregnancy is associated with maternal and fetal complications and must be discouraged or undertaken with great deliberation (Table 4).^{27, 28} The most common cardiovascular complications in patients with Fontan physiology–associated pregnancy are arrhythmia and heart failure. Miscarriages were highly prevalent as was prematurity and intrauterine growth restriction, but no maternal deaths were reported. Anticoagulation is recommended during pregnancy but postpartum hemorrhage seems to be the most common obstetric complication.²⁹ Thus, in patients with a Fontan circulation and saturations <85%, depressed ventricular function, moderate–severe AV regurgitation, refractory arrhythmia, or protein-losing enteropathy, pregnancy is not recommended.

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