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SINGLE VENTRICLE PHYSIOLOGY EPISODE 3: LONG-TERM SCREENING AND MANAGEMENT FOR PATIENTS WITH A FONTAN CIRCULATION

Developed by DR. SABINE LAGUË and DR. SHREYA MOODLEY for PedsCases.com.
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Introduction:

Hello, my name is Sabine Laguë and I am a 1st year pediatrics resident at the University of British Columbia in Vancouver, Canada. I am joined on this podcast today by Dr. Shreya Moodley, a pediatric cardiologist at BC Children's Hospital in Vancouver. I would like to thank Dr. Moodley for her guidance in putting together this podcast, as well as PedsCases.com for their constructive feedback on the script and for this exciting avenue to discuss this interesting topic.

This is the final episode of a three episode podcast series on single ventricle physiology. We are very excited about this series because now more than any time in history we are seeing an increasingly growing number of individuals living and thriving into adulthood with single ventricle physiology post-Fontan palliation. Regardless of the type of medicine you are currently or will end up practicing, it is possible that you will end up working with individuals from this population. Thus, an awareness of Fontan physiology and the systemic complications of this circulation is important.

This third and final episode discusses long-term management and complications associated with the Fontan circulation. We revisit the two hypothetical patients starring in the first two episodes: Jason with tricuspid atresia from the first episode, and Olivia with hypoplastic left heart syndrome from the second episode. Between these two individuals we will cover the main long-term management considerations and complications associated with the Fontan circulation.

Please see the podcast script available on the Pedscases website for helpful figures, tables, and diagrams to help you better understand the underlying cardiac physiology, as well as for summary tables and diagrams outlining long-term complications and management considerations associated with the Fontan circulation.

The objectives of this podcast are to:

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Identify potential sequelae and long-term complications of the Fontan circulation, divided into broad systems or categories:

- I. Cardiac
- II. Endocarditis prophylaxis
- III. Exercise tolerance
- IV. Pulmonary
- V. Gastrointestinal
- VI. Hematologic
- VII. Neuropsychiatric and psychosocial
- VIII. Fertility, contraception, and pregnancy

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You are a general pediatrician and two of your Fontan circulation patients are scheduled to see you today for a routine visit: Jason, now 17 years old, with a history of tricuspid atresia, and Olivia, now 16 years old, with a history of hypoplastic left heart syndrome. You think back fondly to when you first met these two patients back during your 3rd year clerkship.

Having accumulated experience in the care of this population of patients and guided by the literature, you are aware of a number of different potential long-term complications that can be associated with the Fontan circulation, including cardiac, pulmonary, gastrointestinal, endocrine, hematologic, genitourinary, neuropsychiatric, and psychosocial issues.

You are at an outpatient teaching clinic and have a 3rd year resident working with you today. They have familiarized themselves with Jason and Olivia's charts and will be conducting a history and physical exam and reviewing with you prior to you both seeing the patient together.

Your resident knocks on your office door to review, having just seen Jason, a 17-year-old young man who has a Fontan for palliating tricuspid atresia. To learn more about tricuspid atresia and Jason's story, please visit the first episode of this podcast series.

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Resident: Hello! I just had the pleasure of meeting Jason and his parents today. As you are aware, Jason is a 17-year-old young man with a Fontan for surgical palliation of tricuspid atresia. He is here today for a routine follow up.

Staff: Excellent. I'm so glad that you had the opportunity to meet Jason. Both he and Olivia will be excellent teaching cases today for reviewing the long-term management and complications that can be associated with a Fontan or single ventricle circulation.

Let's start with discussing his cardiovascular status. What is a common cardiovascular complication that anyone with a Fontan circulation requires monitoring for (**Figure 1; Table 1**)?

Resident: Arrhythmias. Arrhythmias in this population include sinus node dysfunction, supraventricular and ventricular arrhythmias, junctional rhythms, and atrioventricular block.¹ We monitor for arrhythmias primarily through Holter monitoring or event monitoring when concerning signs or symptoms arise.

Staff: Yes. Atrial tachycardia once developed in over 50% of patients late after Fontan, but modifications of surgical technique have helped to decrease this rate, as direct atrial to pulmonary connections are no longer formed.

Resident: I was reading that the treatment of recurrent or persistent arrhythmias is important in patients with single ventricle physiology, because of the elevated risk of thromboembolic complications and the development of acute heart failure.

Staff: Yes. Frequent arrhythmias can be treated pharmacologically, with surgical revision or Fontan conversion surgery, pacing or catheter ablation in specific cases.

Resident: Jason has been having intermittent palpitations. They are short-lived, however, and he is otherwise asymptomatic and doing well from a cardiovascular perspective, with his most recent echocardiogram unchanged from previous. So right now should we watch and wait?

Staff: Depending on how frequent his episodes are, you could order a Holter monitor or an event monitor to capture the episodes to see if they correlate with arrhythmia. Capturing an abnormal rhythm will help us to characterize it and decide on the appropriate management.

How is Jason doing in terms of his exertional tolerance?

Resident: Currently Jason doesn't feel limited in his day-to-day activities, but he does feel that when it comes to intense exercise he can't keep up with his peers (**Figure 1**).

Staff: Yes, this is supported by literature. Individuals with a Fontan circulation have a maximum oxygen consumption rate that is 43-78% of normal.²⁻⁴ There are a wide variety of potential contributors, including cardiac and extracardiac factors. Cardiac limitations can include impaired chronotropy and limited ability to raise right-sided heart cardiac output.^{5,6} Hypoxemia at rest and during exercise may also play a role, as well as extracardiac limiting factors, such as physical deconditioning, restrictive lung disease and reduced skeletal mass.⁶

Resident: I see. So while several factors could be contributing to decreased intense exercise performance, ultimately if the Fontan circulation is functioning well there should not be significant day-to-day limitations?

Staff: Yes. Can you tell me about the GI complications in patients with the Fontan?

Resident: The primary GI complications that we monitor for in the Fontan population are protein-losing enteropathy and Fontan-associated liver disease (**Figure 1; Table 1**). I was reading in Jason's chart that when he was 8 years old, 5 years after his Fontan surgery, he had long-standing diarrhea and was tested for protein-losing enteropathy. However, thankfully, his testing was negative and his symptoms were found to be due to an infectious cause.

Staff: That's right. Protein-losing enteropathy is a state of hypoalbuminemia caused by intestinal protein loss. The underlying cause of this condition is debated, but it is thought to be due in part to chronic venous hypertension. It has a prevalence of 3-15% and a mortality of 50% at 5 years post-diagnosis.⁷ While it most commonly occurs 2-3 years post-Fontan, it can occur anytime.⁸ Patients often present with chronic edema, ascites, pleural and pericardial effusions, hypoproteinemia and hypoalbuminemia.^{6,9,10} When it comes to monitoring for protein-losing enteropathy, what's the best modality?

Resident: Monitoring for the clearance of fecal α 1-antitrypsin.¹⁰

Staff: Correct. Potential management modalities for protein-losing enteropathy are varied and range from pharmacotherapy to cardiac transplantation.⁷

Resident: Can I ask you some questions about prophylaxis, specifically surrounding endocarditis prophylaxis and thrombosis?

Patients with congenital heart disease and their families frequently ask about whether antibiotic prophylaxis is needed to help prevent infective endocarditis, say during dental visits. In Jason's case, what would you recommend?

Staff: According to the Canadian Cardiovascular Society⁹ and American Heart Association Consensus Guidelines^{4,6} provide guidance on providing antibiotic prophylaxis for patients with congenital heart disease. This includes children with unrepaired cyanotic congenital heart disease, including palliative shunts and conduits, such as the interstage Fontan patient population. In addition, patients who have had previous endocarditis, a redo of their Fontan in the last six months, or cardiac prosthetic material would all be candidates. Interestingly, things like dental cleaning do not actually require SBE prophylaxis, although this is a very common question that we are asked.

Resident: Thanks for that clarification. Regarding thrombosis, I was reading that patients with a Fontan circulation are at lifelong increased risk of thrombosis and thromboembolism, especially stroke and PE (**Figure 1; Table 1**).

Staff: That's right. The incidence of thrombus detection is highest in the first year following Fontan palliation at 8.8%,¹¹ and it is independent of the type of Fontan operation.¹² This high rate of thrombus formation in the first year postop is thought to be secondary to stasis and potentially low cardiac output.⁷ Can you think of other predisposing factors towards the development of thrombi or thromboembolism?

Resident: Patients with a Fontan circulation are at risk of blood flow stasis in the pulmonary arteries, ventricular dysfunction, arrhythmias, protein-losing enteropathy and prolonged immobilization, all of which could increase the risk.¹⁰

Staff: Exactly. Considering the gastrointestinal complications you are aware of, what else may patients with a Fontan circulation be at risk for from a hematological perspective?

Resident: Hepatic dysfunction, coagulopathy, and coagulation factor deficiency.¹³ Wait – so that means that patients with a Fontan circulation may be at risk for both bleeding and clotting?

Staff: That's right. Exact management of the thromboembolic risk in single ventricle patients is controversial and the subject of ongoing investigation, including immediate post-operative anticoagulation and long-term anticoagulation. Many cardiologists now maintain their patients on aspirin although some may continue to use warfarin or combination therapy in higher risk patients.

We've discussed a lot of the basic medicine surrounding long-term follow up of Fontan patients, but a core aspect of their care is regarding their neuropsychiatric and psychosocial wellbeing. What can you tell me about that?

Resident: I had the opportunity to conduct a HEADSSS exam with Jason alone. This is the psychosocial screen we use for adolescent patients. We discussed his home environment, education, employment, eating habits, activities, drugs, sexuality, mental health, and suicide.

Staff: Excellent. We should be conducting this inventory on all of our adolescent patients, regardless of their presenting complaint, as it often helps to identify additional concerns and topics that can be addressed regarding risk management, prevention, and mental health.

Resident: Jason confided in me that a lot of his friends started trying vaping. We explored his feelings around the issue. He is aware of recent negative stories in the media surrounding vaping, and said that given his underlying medical conditions he really wanted to do everything he could to try to stay healthy, so he hasn't tried vaping yet. I commended him for his insight and maturity and reiterated that we strongly recommend not vaping, given the potentially catastrophic effects that it can have on his lungs and neurological development.^{14,15}

Staff: Thank you for having this important discussion with Jason. It's especially important in this context to explore all aspects of the HEADSSS exam because adolescents and young adults with complex cyanotic heart disease are at a higher risk of problems with executive function (**Figure 1**). What's your understanding of executive function?

Resident: Executive function is the skills necessary for regulating behaviour, emotion, social adaptation, and cognition. Abnormal executive function can manifest itself as difficulties with planning, inhibition, cognitive flexibility, working memory, and attention.¹⁶

Staff: Excellent. As a result, these individuals may be more vulnerable to participate in risk-taking behaviour. This highlights the importance of exploring risk-taking behaviours and providing appropriate counseling within the context of a positive therapeutic relationship.

Staff: Knowing Jason, did anything else come up when you were talking about school?

Resident: Jason mentioned that he has ADHD. He's being treated with a combination of pharmacotherapy and behavioural modification. He hasn't had any major side effects from the medications, including anorexia, insomnia, or hypertension. He is performing well in school and has been receiving Bs. Given his new finding of palpitations, I imagine we will have to review his list of medications?

Staff: Yes. Congenital heart disease has a complex and multifaceted impact on development (**Figure 1; Table 1**). In general, the more severe the cyanotic congenital heart lesion, the greater potential longstanding risk to altered neurodevelopment and neuropsychiatry. Are you aware of some factors that increase the risk for neuropsychiatric or developmental issues in congenital heart disease?

Resident: The risk factors contributing these issues are complex and multi-factorial. Risk factors include congenital brain anomalies, comorbid genetic syndromes or chromosomal abnormalities, prenatal versus postnatal diagnosis, and socioeconomic status.⁷ All of these risk factors must be considered when providing counseling and determining the underlying cause of any developmental delay.

Staff: Precisely. In what ways can the development and behaviour of individuals with a Fontan circulation be impacted?

Resident: Children and adolescents with severe cyanotic congenital heart disease who had cardiac surgery as infants are at higher risk of exhibiting delays in many areas of functioning, including delays or deficits in executive function, psychosocial functioning, and in motor development, as well as a higher incidence of behavioural challenges, particularly attention-deficit/hyperactivity disorder (ADHD), like Jason (**Figure 1**).^{7,17}

Staff: In patients with a single ventricle, lower gestational age at birth is a significant risk factor for developing such conditions. Patients born slightly earlier in gestation (i.e. 37-38 weeks) compared to those born at full-term (≥ 39 weeks gestation) have a greater prevalence of executive dysfunction, ADHD diagnoses, and psychiatric diagnoses.¹⁷ While routine developmental screening is suggested beginning in infancy in all single ventricle patients to allow for earlier potential intervention,¹⁸ patients born at earlier gestational ages should receive closer developmental surveillance.

Resident: How is their school performance and quality of life impacted?

Staff: Outcomes related to school performance and behaviour are variable in the literature, with some subjective studies reporting little impact on academic performance and overall wellbeing,¹⁹ and others indicate a larger impact on attention and learning.²⁰ Further research is needed into the areas of neurodevelopmental outcomes, quality of life, and comorbid psychiatric conditions in patients with critical congenital heart disease.

Resident: Children and families living with these complex congenital heart conditions experience both physical and psychosocial challenges, including the need for repeat interventions, chronic medication use, uncertainty regarding long-term prognosis, persistent symptoms, and possible developmental delay.⁷ Given that these factors can impact one's quality of life, this population may be at higher risk for depression and should undergo appropriate screening.¹

Staff: While these factors may certainly impact one's quality of life, it would be incorrect to assume that negative outcomes or a negative quality of life are inevitable, as quality of life is highly multifaceted and subjective.⁷ Regardless, it is imperative that healthcare practitioners have an appreciation of these significant elements and their potential impact on quality of life and function, providing appropriate screening and intervention where necessary.

Satisfied with how your resident is beginning to grasp some of the multi-system long-term management and complications that can occur with a Fontan circulation, you both go to meet with Jason and his parents.

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After lunch, your resident knocks on your door, having just met with Olivia, a 16-year-old young woman with a Fontan circulation to palliate hypoplastic left heart syndrome. To learn more about hypoplastic left heart syndrome and Olivia's story, please visit the second episode in this podcast series.

Resident: Hello! I just had the pleasure of meeting Olivia and her mother. Olivia is a 16-year-old young woman that we have been following. She has a Fontan for hypoplastic left heart syndrome. She is here today for a routine follow up.

Staff: Excellent. Why don't you start by reminding me what the main cardiac complications are that we screen for or are concerned about in individuals with a Fontan circulation.

Resident: Regular cardiac monitoring for Fontan patients includes monitoring of hemodynamics, shunting, arrhythmias, and structure and function of outflow tracts and valves (**Figure 1; Table 1**). We monitor for these predominantly using echocardiography and ECG, though there is a role for cardiac magnetic resonance imaging (MRI) and interventional catheterization.

I've found that the Canadian Cardiovascular Society⁹ (Silversides et al., 2010) and the American Heart Association^{4,6} both have good consensus guidelines for discussing the management of children and adults with congenital heart disease and with a Fontan circulation.

Staff: Hemodynamic abnormalities can develop gradually in Fontan patients. What are some red flag signs and symptoms that would make you concerned?

Resident: Desaturation at rest or during exercise, decreased exercise tolerance, or the presence of a new murmur or hepatomegaly on exam.¹

Staff: Yes, these are a few of the many different signs that might lead to concern. We have been routinely monitoring Olivia through routine echocardiography for these signs and symptoms, as well as for others. We specifically investigate for aortic arch obstruction, as well as for ventricular systolic and diastolic function, because ventricular dysfunction can occur. We also investigate for valvular stenosis or regurgitation, as atrioventricular valve regurgitation is poorly tolerated by single ventricle physiology.²¹

Can you think of any reasons why a single ventricle patient may have cyanosis post surgery?

Resident: Cyanosis might indicate arteriovenous malformations, veno-venous collaterals, or the presence of a fenestration.¹⁰

Staff: Correct. Those are good examples of lesions that can cause cyanosis. While Olivia has been relatively asymptomatic from a cardiac perspective, she does have a significant history with regards to developing a rare pulmonary complication.

Resident: Yes. I was reading in Olivia's chart that 6 months following her Fontan operation she developed plastic bronchitis, a rare but potentially fatal complication that can occur weeks to months postop (**Table 1**). Plastic bronchitis leads to obstruction of the major airways by solid fibrinomuroid material. Its pathophysiology is unknown, but it is thought to be caused by chyle or other proteinaceous material leaking into the airways causing bronchial casts.^{1,22} Fontan-associated plastic bronchitis is believed to be caused by protein-rich lymph spilling through lymphatic-to-bronchial communications.⁶ Olivia

presented with tachypnea, wheezing, and a chronic productive cough.¹ Fortunately she was being carefully monitored during this time and received prompt diagnostic and therapeutic bronchoscopic lavage. I'm a little unclear how she was treated for it, however.

Staff: Treatment for plastic bronchitis is similar to protein-losing enteropathy, and should include symptomatic therapy as well as a careful investigation of the Fontan circulation for anatomic abnormalities. Therapy may include pharmacotherapy such as diuretics, bronchodilators and steroids to cardiac transplantation and other procedures aimed at decreasing venous pressure.^{6,10} Fortunately, Olivia responded well to medical therapy as well as revision of her conduit and has been reasonably well since.

Moving through our review of systems to GI, we've already discussed protein-losing enteropathy with Jason. Another significant GI complication associated with Fontan circulation is Fontan-associated liver disease (**Figure 1; Table 1**), which has only recently started to be described because of the increasing number of patients surviving years with their Fontan. What can you tell me about this condition?

Resident: Fontan-associated liver disease is the result of long-term hepatic congestion, because Fontan patients have an average central venous pressure that is 3-4 fold higher.²³ It can lead to disturbances in liver enzymes and clotting factors, cardiac cirrhosis, and hepatic adenoma and hepatic carcinoma.²⁴

Staff: That's right. Assessment of liver function has steadily improved over the years as we have started to understand liver disease in the Fontan patient a bit better. Now we can perform liver surveillance through history, physical exam, lab work and various imaging modalities.

Resident: I also had the opportunity to conduct a HEADSSS exam with Olivia alone. A major topic that came up was that Olivia wants to discuss her contraceptive options and she has questions regarding how Fontan circulation might impact pregnancy.

Staff: Contraception and pregnancy are very important topics in the Fontan population. Can you think of some reasons why this might be the case?

Resident: Pregnancy is a physiological challenge for any woman as there are many hemodynamic changes with an impact on the cardiovascular system. It is also known to worsen clinical outcomes in patients with certain comorbid cardiac pathologies.²⁵ Women with a Fontan circulation have an increased risk of maternal and fetal morbidity and mortality during pregnancy, and also differ from the general population in many aspects of fertility and childbearing (**Figure 1**).

Staff: That's right. Women with a Fontan circulation have delayed-onset fertility, with menarche occurring later in adolescence.²⁵ While their cyanotic circulation has been implicated in this delay, it's not explicitly proven, though it has been noted that menarche occurs later in women with concurrent cyanosis and more severe cardiac defects.²⁶

While all women need to balance the risks of pregnancy with the efficacy of their chosen contraceptive method, it is especially important in the Fontan circulation because these patients need to consider possible cardiac sequelae associated with both their contraceptive method and as well as with pregnancy.²⁵

Can you think of a potential problem with a commonly used contraceptive?

Resident: The oral contraceptive pill increases the risk of thromboembolism, and people with a Fontan circulation are already at an increased risk of thrombus development.

Staff: That's right. Various methods of contraception are possible and often consultation with the cardiologist and gynecologist can be helpful to decide on the best method for a particular patient.

Resident: These are a lot of different factors to consider. I imagine that pre-pregnancy counseling is important in this population.

Staff: Pre-pregnancy counselling is of the utmost importance in the Fontan population. Both the Canadian Cardiovascular Association and American Heart Association have Class I recommendations that prior to pregnancy all women with Fontan circulation need comprehensive cardiovascular evaluation by a physician experienced with adult congenital heart disease.²⁷

What are some of the cardiovascular risks associated with pregnancy in the single ventricle or Fontan population?

Resident: Pregnancy places an increased hemodynamic burden on the single ventricle and atrium, as well as increases the risk of maternal atrial arrhythmia, thromboemboli, and ventricular dysfunction, and may worsen valvular regurgitation and systemic venous congestion.

Arrhythmias in pregnant women pose a high risk for both mother and fetus, with higher rates of miscarriage, intrauterine growth restriction, and prematurity. Thromboembolism is a significant risk during pregnancy, and prophylactic anticoagulation during pregnancy and postpartum should be considered.²⁸

Staff: Correct. The most significant unknown in this area of research is whether the increased cardiac volume that occurs during pregnancy has negative long-term effects on women with a Fontan circulation, as has been shown in other cases of congenital cardiac defects, such as patients with congenital aortic stenosis,²⁹ or dilated cardiomyopathy.³⁰

Despite these current gaps in knowledge, we do know that there are increased risks to the fetus of a woman with Fontan circulation, including increased frequency of spontaneous abortion, intrauterine growth restriction, and preterm birth.⁹

Pregnancy data in the Fontan population is limited, and comparisons between studies are difficult because rates of miscarriage or medical termination may be underreported. Women in this population are known to have higher rates of miscarriage - 42-57% - compared to 20% in the general population. 71% of successful pregnancies lead to a premature birth, delivering <37 weeks gestation.²⁵

What do you know about infant development born to mothers in this population?

Resident: Infant developmental outcomes based on prematurity are comparable to the general population, but it is unknown whether there are long-term neurodevelopmental effects in those mothers who may be hypoxic.

So what's the bottom-line when it comes to counseling women with a Fontan circulation about pregnancy?

Staff: Current literature supports that there is significant maternal morbidity associated with pregnancy, but not necessarily increased mortality. While there are women with a Fontan circulation in whom pregnancy would certainly be contraindicated, for the general well-woman with an appropriately functioning Fontan circulation, pregnancy should not be contraindicated.²⁵ It is imperative to receive expert pre-pregnancy counseling from an individual specifically trained in caring for people with adult congenital heart disease, as well as receiving expert antenatal care.

Satisfied with your resident's understanding of the multi-system long-term management and complications that can occur with a Fontan circulations, you summarize the main systems requiring surveillance and potential complications arising from the Fontan circulation. These are also summarized in Figure 1 and Table 1 in the show notes.

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At present we have the largest cohort of individuals with a Fontan or single ventricle circulation. Physicians and medical learners will see these individuals in all areas of medicine, and thus it is important to have a basic understanding of the physiology, as well as different complications that can arise from having a Fontan physiology. The main short- and long-term complications that can arise from a Fontan circulation are documented in Figure 1 and in Table 1. Working from head to toe, the possible complications a physician should be aware of are as follows:

Neuropsychiatric and psychosocial: developmental delay, altered executive function, ADHD, depression, potentially altered quality of life

Endocrine: thyroid dysfunction

Cardiac: ventricular dysfunction (systolic/diastolic), arrhythmias, AV valve dysfunction, aortopathy, possible need for perioperative endocarditis prophylaxis, cyanosis

Exercise tolerance: decreased exercise capacity

Pulmonary: increased pulmonary resistance, pulmonary arteriovenous fistulae, pulmonary arteriovenous malformations, plastic bronchitis

Gastrointestinal: Fontan-associated liver disease (liver congestion, cirrhosis, hepatocellular carcinoma), protein-losing enteropathy, synthetic liver dysfunction, impaired nutrition

Hematologic: coagulopathies, thromboembolism, anemia, polycythemia

Fertility, contraception, and pregnancy: delayed menarche, increased rate of miscarriages and premature birth, need for specialized medical follow-up pre-pregnancy and prenatally

Constitutional: growth

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Recommended resources for learners

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Neuropsychiatric

- developmental delay
- cerebrovascular accident
- executive dysfunction
- ADHD
- depression

Endocrine

- thyroid dysfunction

Cardiovascular

- ventricular dysfunction (systolic, diastolic)
- arrhythmias
- AV valve dysfunction
- cyanosis
- endothelial dysfunction

Gastrointestinal

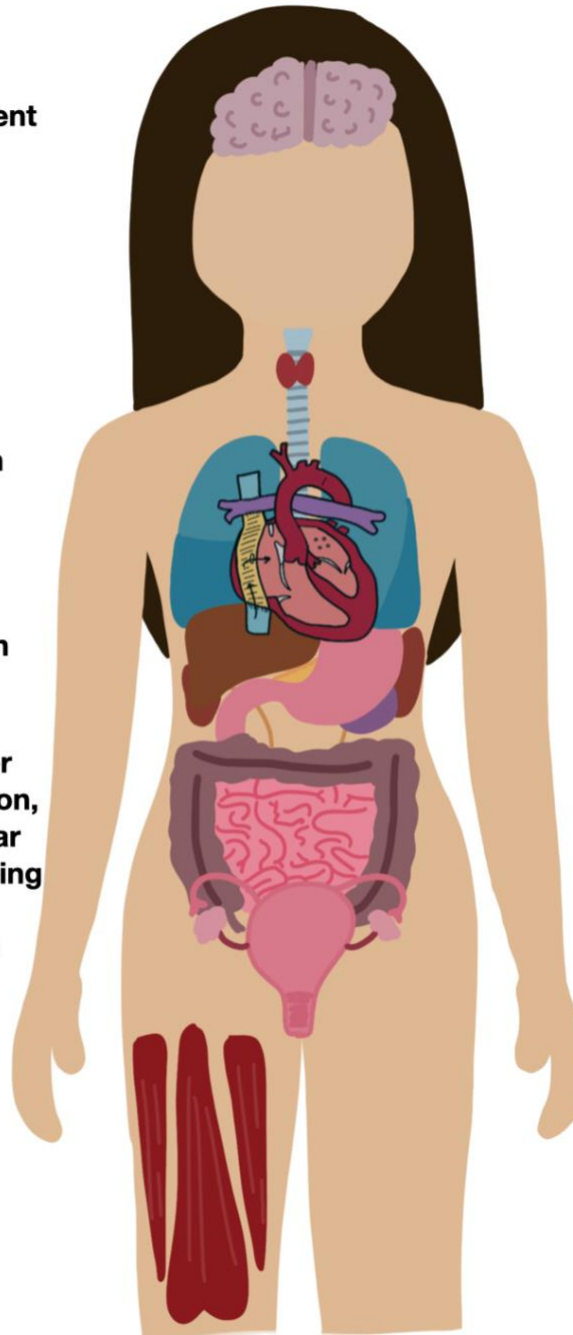
- Fontan-associated liver disease (liver congestion, cirrhosis, hepatocellular carcinoma, protein-losing enteropathy)
- synthetic liver function
- impaired nutrition

Exercise capacity

- decreased capacity
- impaired muscle metabolism

Constitutional

- growth



Psychosocial

- potentially altered quality of life

Respiratory

- increased pulmonary resistance
- plastic bronchitis
- pulmonary arteriovenous fistulae

Hematological

- coagulopathies
- thromboembolism
- anemia
- polycythemia

Renal

- cardiorenal syndrome
- hepatorenal syndrome
- protein-losing enteropathy

Genitourinary

- delayed menarche
- increased rate of miscarriages
- increased premature birth

Figure 1: Short-term and long-term complications sequelae that can occur in patients with a Fontan circulation. Figure by S. Laguë.

Childhood Organ System Surveillance Testing			
Organ System	Basic	In-Depth	Investigational
Liver	Comprehensive metabolic panel	PT/INR	Liver imaging via CT or MRI
	Platelet count	Serum FibroSure biomarkers	Liver elastography (ultrasound or MRI)
	Serum GGT	Serum alpha-fetoprotein	Liver biopsy
		Abdominal (liver) ultrasound	
		Total serum cholesterol	
Kidney	Serum BUN, creatinine	Urinalysis, albumin/creatinine ratio	Renal ultrasound with Doppler
	Serum cystatin C		Nuclear scan GFR
Lymph	Serum albumin, total protein	Serum IgG	T2-weighted MRI lymphatic imaging
	Absolute lymphocyte count	Fecal alpha-1 antitrypsin level	
Endocrine/metabolic	Serum calcium	Parathyroid hormone	Serum insulin-like growth factor
	Vitamin D	Bone densitometry/DXA scan	
	Tanner staging, developmental assessment	Nutritional evaluation and consultation	
Heme	CBC, hemoglobin, hematocrit	Serum iron	Coagulation factors
		TIBC	
		Ferritin	
Lungs		Chest x-ray	Pulmonary function testing
Neurological/psychological	Neurodevelopmental/cognitive testing	Psychological evaluation and consultation	Brain MRI scanning
Adolescent Organ System Surveillance Testing			
Organ System	Basic	In-Depth	Investigational
Liver	Comprehensive metabolic panel	Serum FibroSure biomarkers	Liver biopsy
	Platelet count	Serum alpha-fetoprotein	
	Serum GGT	Abdominal (liver) ultrasound	
	PT/INR	Total serum cholesterol	

		Liver imaging via CT or MRI	
		Liver elastography (ultrasound or MRI)	
Kidney	Serum BUN, creatinine	Urinalysis, albumin/creatinine ratio	Nuclear scan GFR
	Serum cystatin C	Renal ultrasound with Doppler	
Lymph	Serum albumin, total protein	Serum IgG	T2-weighted MRI lymphatic imaging
	Absolute lymphocyte count	Fecal alpha-1 antitrypsin level	
Endocrine/metabolic	Serum calcium	Parathyroid hormone	Serum insulin-like growth factor
	Vitamin D	Bone densitometry/DXA scan	
	Tanner staging, developmental assessment		
	Nutritional evaluation and consultation		
Heme	CBC, hemoglobin, hematocrit	Serum iron	Coagulation factors
		TIBC	
		Ferritin	
Lungs		Chest x-ray	Pulmonary function testing
Neurological/psychological	Neurodevelopmental/cognitive testing	Psychological evaluation and consultation	Brain MRI scanning

Table 1: American Heart Association proposed childhood and adolescent organ system surveillance testing for people with a Fontan circulation. Adapted from Rychik et al. (2019).⁶ BUN indicates blood urea nitrogen; CBC, complete blood count; DXA, dual-energy x-ray absorptiometry; GFR, glomerular filtration rate; TIBC, total iron-binding capacity.