

Fontan failure associated with a restrictive systemic ventricle

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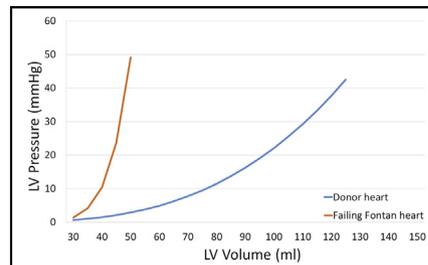
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End-diastolic pressure–volume relationship measurement of the explanted ventricle, confirming the restrictive physiology.

Central Message

We report a case of progressive failure of the Fontan physiology associated with a restrictive physiology. We attribute this restrictive physiology to chronic volume deprivation of the ventricle.



Video clip is available online.

We report a case of progressive failure of the Fontan physiology with therapy-refractory protein-losing enteropathy (PLE) requiring cardiac transplantation. We expected a severely restrictive systemic ventricle, which was confirmed by direct measurement of the compliance of the explanted ventricle. We attribute the restrictive physiology to sustained “disuse hypofunction” because of chronic volume deprivation of the systemic ventricle.

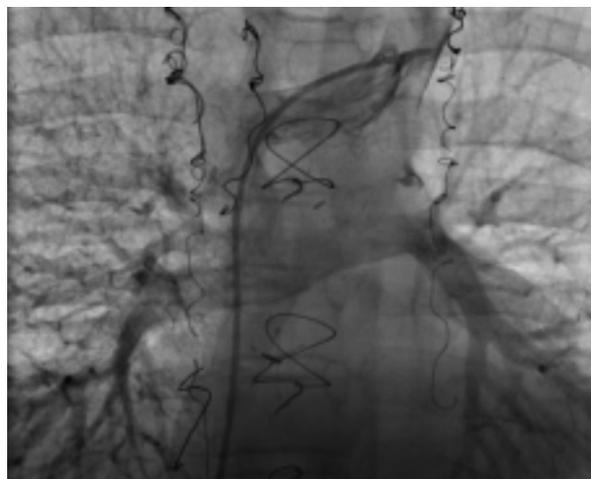
CLINICAL SUMMARY

The patient was a 15-year-old girl with a double inlet left ventricle univentricular heart and a large ventricular septal defect. She underwent pulmonary artery banding in infancy, followed by a bidirectional Glenn shunt at 18 months of age. Fontan completion with a fenestrated extracardiac conduit was performed at 3 years of age. The fenestration was closed percutaneously (15-mm PFO-STAR; Cardia, Burnsville, Minn) 1 year later. The patient developed PLE a couple of months after closure of the fenestration. During the ensuing 12 years, follow-up examinations showed frequent exacerbations of PLE and a progressive decline in exercise capacity despite treatment with high-dose diuretics, corticosteroids, and sildenafil. Heart catheterization showed an unimpeded flow to the pulmonary arteries (Video 1). There was a normal systolic function but a severely reduced cardiac index of 1.8 L/(min · m²) and an estimated pulmonary vascular resistance index of 2.2 U · m² ((mm Hg/L/min) · m²). Venous pressure was 20 mm Hg, left atrial pressure was 16 mm Hg, and after a fluid challenge (600 mL), ventricular end-diastolic pressures increased to 28 mm Hg.

Because of the clear association between closure of the fenestration and the development of PLE, we discussed

reopening the fenestration. This option was not further pursued after we considered the technical difficulties involved in reopening the device-closed fenestration. The patient was listed for heart transplant and in April 2015 underwent successful heart transplantation.

Immediately after explants, we performed passive, end-diastolic pressure–volume relationship (EDPVR) measurements on the explanted heart.¹ A balloon was



VIDEO 1. Catheterization of the Fontan connections, illustrating an unobstructed flow to the pulmonary arteries. Video available at: <http://www.jtcvs.org>.

Case Report

connected to an infusion cannula and pressure sensor. The balloon was inserted in the ventricle through the mitral valve. Pressure was measured at incremental saline infusions. Ventricular volume was corrected for the volume of the balloon wall and ventricular pressure was corrected for the passive EDPVR of the balloon. Results were compared with EDPVR measurements of an unused adult cardiac allograft (Figure 1). The EDPVR of the patient who underwent a Fontan procedure was shifted toward smaller volumes because of the smaller size of the Fontan ventricle. The slope of the Fontan EDPVR was much steeper, suggesting a lower compliance of the Fontan ventricle independent from size. Macroscopic evaluation of the explant heart showed a small ventricle with a normal wall thickness. Histologic evaluation by a pathologist, after staining with hematoxylin and eosin and Sirius red, revealed no signs of hypertrophy, fibrosis, or myocardial disarray (Figure 2).

DISCUSSION

Failure of the Fontan circulation often is attributed to ventricular dysfunction, pulmonary vascular remodeling, or obstruction of the Fontan connections. In our case, the development of a restrictive physiology became a major contributing factor to Fontan failure. The characteristic restrictive filling of the ventricle was documented by EDPVRs that showed a marked decrease in ventricular compliance. We hypothesize that this restrictive physiology was secondary to long-standing volume deprivation of the ventricle. This severe chronic volume deprivation of the ventricle has led to progressive “disuse hypofunction,” with eventually the development of a restrictive cardiomyopathy that accounts for the observed severe diastolic ventricular dysfunction with reduced compliance and increased filling pressures.²

When the heart is exposed to an acute reduction in preload, as after the administration of diuretics or venodilators, there is a progressive decrease in end-diastolic volume, end-

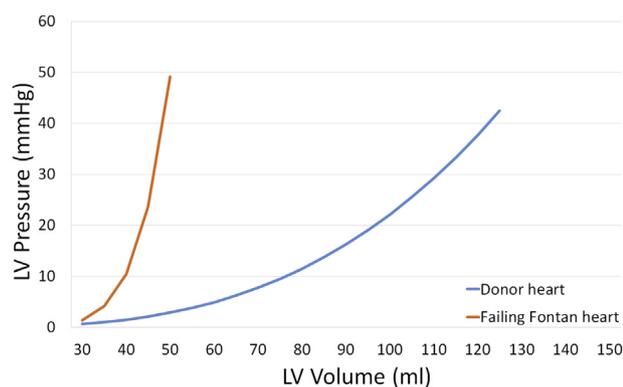


FIGURE 1. Passive, ex vivo pressure–volume relationship from our patient with failing Fontan circulation and a control cardiac allograft. LV, Left ventricular.

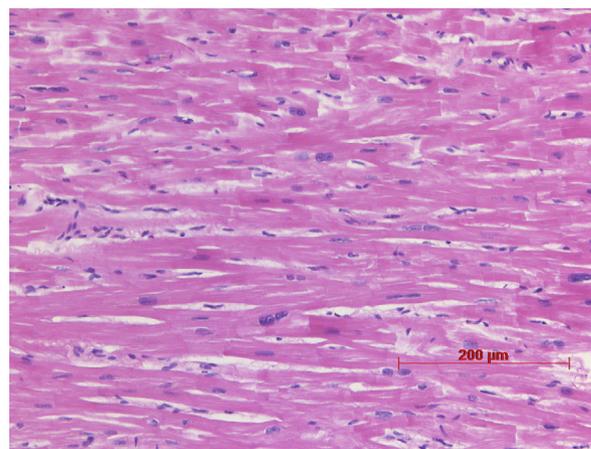


FIGURE 2. Hematoxylin and eosin–stained sample of myocardial tissue. The normal organization of myocardial fibers is preserved without signs of hypertrophy or fibrosis.

diastolic pressure, end-systolic volume, and stroke volume. Chronic volume deprivation, however, is a rare and largely unknown phenomenon. There has been some interest in the effects of chronic volume deprivation in patients with mitral stenosis.^{3,4} These studies demonstrate that a chronic deprivation of preload leads to a gradual increase in end-diastolic pressure and a decrease in ventricular compliance; this leads to poor ventricular filling and progressive decline of cardiac output.

A study on diastolic function in patients with Fontan circulation demonstrated a similar reduction in ventricular compliance.⁵ The finding in our case that this reduced compliance was not associated with any myocardial fibrosis or hypertrophy suggests that it was not primarily the result of remodeling and/or atrophy. Instead, our observations suggest that the compliance reduction was a consequence of a functional restriction caused by chronic low preload. Because currently our findings fail to understand the mechanisms behind this functional restriction, more research will be necessary to verify this theory and to provide us with a better understanding of the anatomical or physiological changes that result in this restrictive physiology.

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