**Ventricular Square-Wave Response**

**Case Illustrating the Role of Invasive Hemodynamics in the Management of Continuous-Flow Left Ventricular Assist Device Dysfunction**

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First described in 1704, the Valsalva maneuver is a well-established noninvasive approach to assessing volume status and ventricular filling pressures in a patient with heart failure. During phase I of the Valsalva maneuver intrathoracic pressure increases and blood pressure rises. Phase II is associated with increased intrathoracic pressure and reduced left ventricular (LV) preload, which reduces arterial pressure. Intrathoracic pressure decreases with release of the strain phase (phase III), and blood pressure overshoots and returns to baseline (phase IV). In a patient with congestive heart failure, the strain phase of the Valsalva maneuver does not exhibit the typical declining slope of arterial pressure and is recognized as the square wave response. No reports have described the effect of the Valsalva maneuver in patients with a durable LV assist device (LVAD). We describe a case illustrating the potential use of the Valsalva maneuver in a LVAD patient who had developed an outflow graft stenosis.

A 35-year-old man with long-standing stage D dilated, nonischemic cardiomyopathy with a LV ejection fraction of 15% and body mass index of 42 kg/m², underwent implantation of an HW-LVAD (Heartware; Framingham, MA) as a bridge to decision strategy. Two years after LVAD implantation, he presented with intravascular hemolysis (peak lactate dehydrogenase, 5204 ng/dL) and power spikes suggestive of LVAD thrombosis despite an international normalized ratio of 3.0. He underwent successful LVAD exchange for a second HW-LVAD device with resolution of clinical and biochemical markers of LVAD thrombosis. One year later he presented with recurrent hemolysis (LDH, 1578 ng/dL) with an international normalized ratio of 2.0. An echocardiographic ramp study confirmed failure to unload the LV. Noninvasive imaging revealed a stenosis at the anastomosis of the LVAD outflow graft to the ascending aorta (Figure 1). Initial therapy with bivalirudin improved his hemolysis parameters.

An invasive hemodynamic study was performed via the left radial artery and a double-lumen pigtail catheter (Vascular Solutions, Maple Grove, MN) to assess the severity of the outflow graft obstruction and LVAD function. The pigtail catheter was first inserted into the LVAD outflow graft and showed no gradient within the graft itself; however, a 45-mmHg mean gradient was recorded across the aortic anastomosis. Next, we interrogated LVAD function by placing the pigtail across the aortic valve. At 3000 rpm, the resting LV to aortic systolic pressure waveform showed no gradient (Figure 2, phase I), suggesting incomplete LV unloading by the LVAD. A Valsalva maneuver demonstrated no change in the LV to aortic peak systolic pressure or gradient during the strain phase (Figure 2, phase II). During recovery (Figure 2, phases III–IV), improvement in LV systolic pressure was blunted. Using a 90-cm 7F vascular sheath placed in the ascending aorta via the right femoral artery, we treated the stenotic outflow graft lesion with a 10 mm × 27 mm Visi-Pro balloon-expandable stent (Covidien, Plymouth, MN), which resolved the outflow gradient to <10 mmHg. Repeat interrogation of the LV at 3000 rpm with the pigtail catheter now revealed a low LV systolic pressure, increased aortic pressure and a 20 mmHg resting gradient between the LV and aorta (Figure 2, phase I), suggesting improved LV unloading by the LVAD. During the strain phase of the Valsalva maneuver, we observed a gradual decline in peak LV systolic pressure and no change in aortic pressure (Figure 2, phase II). During recovery (Figure 2, phases III–IV), improvement in LV systolic pressure was brisk. Seven month later he remains free of recurrent LVAD dysfunction.

The use of continuous flow-LVADs has increased exponentially during the past decade with >3000 implants in 2013 alone. LVAD thrombosis is an uncommon complication of device therapy and is often managed with antithrombotic therapy or device exchange. LVAD outflow graft stenosis is rare and can require surgical revision. Diagnostic evaluation of LVAD dysfunction involves biochemical markers of hemolysis, echocardiographic ramp studies, and less commonly invasive hemodynamic interrogation. Unlike echocardiography, hemodynamic evaluation provides a direct examination of LV loading conditions. In this report, we describe a case...
of probable LVAD thrombosis and outflow graft stenosis in the same patient and further show that the Valsalva maneuver demonstrated a ventricular square-wave response that immediately resolved after treatment of the outflow graft stenosis. Further evaluation of the clinical utility of the Valsalva maneuver in LVAD patients is required. These findings suggest that in select cases, invasive hemodynamic evaluation of the outflow graft and ventriculo-arterial coupling combined with the Valsalva maneuver is an important part of the evaluation of LVAD dysfunction when other diagnostic parameters fail.

Disclosures

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References


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Figure 1. Fluoroscopic images of (A) the double-lumen pigtail being placed into the outflow graft of the left ventricular assist device and (B) being pull-back of the pigtail across the aortic anastomosis. C, Pressure tracings from the double-lumen pigtail showing no gradient within the outflow graft and a significant gradient across the aortic anastomosis.
Figure 2. Simultaneous hemodynamic tracings of the left ventricle (LV), aortic root, and pulmonary artery before (A) and after (B) stenting of the LV assist device outflow graft. Phases of the Valsalva maneuver are labeled as (I, II, III, and IV).
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