Computational fluid dynamics visualizes turbulent flow in the aortic root of a patient under continuous-flow left ventricular assist device support

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Retrograde turbulence in the aortic root during LVAD support.

Central Message

We analyzed retrograde spiral turbulent flow in the aortic root during CF-LVAD support using CFD with accurate detailed anatomy.

See Commentaries on pages e209 and e211.

▶ Video clip is available online.

Aortic insufficiency (AI) developed during continuous-flow left ventricular assist device (CF-LVAD) use occurs in 25% of patients within 1 year of CF-LVAD implantation.^{1,2} Nonphysiologic retrograde flow in the ascending aorta and shear stress in the aortic valve have been suggested to induce valve-leaflet thinning, consequently, AI and its progression.^{3,4} Although blood flow analysis using vector flow mapping with 2-dimensional echocardiographic images or computational fluid dynamics (CFD) using the aortic

mold without aortic root has been reported, blood flow and shear stress in the 3-dimensional aortic root with its complex anatomy are unknown.^{4,5} To evaluate the 3-dimensional blood flow, CFD analysis with an accurate aortic root anatomy, including the aortic valve and coronary arteries, was performed in a 40-year-old woman in whom the aortic valve did not open after

FIGURE 1. A, Graph representing the time-dependent change in the arterial pressure during 1 cardiac cycle in patients with ischemic cardiomyopathy under CF-LVAD support. B, Graph representing the time-dependent change in the flow rate from the LVAD during 1 cardiac cycle, which was calculated using the arterial pressure waveform and mean cardiac output (4.0 L/min) in the Swan-Ganz catheter. C, Images showing a 3-dimensional patient-specific geometry of the aorta, the coronary and cervical arteries, and the outflow graft of the LVAD from the anterior (*left*), lateral (*middle*), and inferior (*right*) view.

FIGURE 2. The results of CFD simulation in a patient supported with a CF-LVAD. A, Streamline shows retrograde spiral turbulence in the aortic root. B, Shear stress is low in the aortic root except in the coronary arteries. C, Shear stress is similar in each aortic valve cusp and relatively high in the commissures. D, Oscillatory shear index in the aortic root is low.

CF-LVAD (HeartMate II, Abbott, Chicago, Ill) implantation for ischemic dilated cardiomyopathy. First, the accurate flow rate was calculated using the arterial pressure waveform and cardiac output in the Swan-Ganz catheter (Figure 1, A and B), and a 3-dimensional patient-specific geometry was created using AZE Virtual Place (AZE, Tokyo, Japan) with electrocardiogram-gated computed tomography images (Figure 1, C). Subsequently, CFD analysis, using ANSYS-FLUENT 18.0 (ANSYS, Inc, Canonsburg, Pa), revealed retrograde spiral turbulence in the aortic root (Figure 2, A, Video 1), similar to a previous study that used echocardiography,⁴ and demonstrated a low shear stress in the aortic root excluding the coronary arteries (Figure 2, B, and Video 2). Shear stress was similar in each aortic valve cusp, whereas it was relatively high in the commissures (Figure 2, C, and Video 3). The oscillatory shear index in the aortic root was low (Figure 2, D).

VIDEO 1. Streamline during 1 cardiac cycle from CFD simulation in a patient supported with a CF-LVAD showing retrograde spiral turbulence in the aortic root. Video available at: [https://www.jtcvs.org/article/S0022-5223\(19\)30284-3/fulltext](https://www.jtcvs.org/article/S0022-5223(19)30284-3/fulltext).

VIDEO 2. Shear stress during 1 cardiac cycle from CFD simulation in a patient supported with a CF-LVAD, showing low shear stress in the aortic root except in the coronary arteries. Video available at: [https://www.jtcvs.org/article/S0022-5223\(19\)30284-3/fulltext](https://www.jtcvs.org/article/S0022-5223(19)30284-3/fulltext).

Elucidation of the difference in blood flow pattern and shear stress between patients with and without de novo AI might allow preoperative CFD to predict AI occurrence after CF-LVAD implantation.

References

1. Bouabdallaoui N, El-Hamamsy I, Pham M, Giraldeau G, Parent MC, Carrier M, et al. Aortic regurgitation in patients with a left ventricular assist device: a contemporary review. *J Heart Lung Transplant*. 2018;37:1289-97.
2. Toda K, Fujita T, Domae K, Shimahara Y, Kobayashi J, Nakatani T. Late aortic insufficiency related to poor prognosis during left ventricular assist device support. *Ann Thorac Surg*. 2011;92:929-34.

VIDEO 3. Shear stress in the aortic valve during 1 cardiac cycle from CFD simulation in a patient supported with a CF-LVAD, showing that shear stress is similar in each aortic valve cusp and is relatively high in the commissures. Video available at: [https://www.jtcvs.org/article/S0022-5223\(19\)30284-3/fulltext](https://www.jtcvs.org/article/S0022-5223(19)30284-3/fulltext).

3. Hata H, Fujita T, Ishibashi-Ueda H, Nakatani T, Kobayashi J. Pathological analysis of the aortic valve after long-term left ventricular assist device support. *Eur J Cardiothorac Surg*. 2014;46:193-7.
4. Yoshida S, Fukushima S, Miyagawa S, Toda K, Sawa Y. Visualization of vortex flow and shear stress in the aortic root during left ventricular assist device support. *J Thorac Cardiovasc Surg*. 2017;154:877-8.e871.
5. Karmonik C, Partovi S, Loebe M, Schmack B, Weymann A, Lumsden AB, et al. Computational fluid dynamics in patients with continuous-flow left ventricular assist device support show hemodynamic alterations in the ascending aorta. *J Thorac Cardiovasc Surg*. 2014;147:1326-33.e1321.