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EDITORIAL COMMENTARY

Optimizing hepatic flow distribution with the Fontan Y-graft: Lessons from computational simulations

Elaine Tang, BEng,^a and Ajit P. Yoganathan, PhD^b

See related article on pages 247-55.

Pulmonary arteriovenous malformations and thrombosis are 2 of the many long-term complications affecting patients with single-ventricle Fontan circulation. Pulmonary arteriovenous malformations have been related to the unbalanced distribution of hepatic nutrients to the 2 lungs.^{1,2} It has been shown that the flow phenomena in a blood vessel can be related to thrombus formation, and platelets preferentially adhere in low-shear zones.³ A bifurcated venous graft design, named "Optiflo," was proposed by

Soerensen and associates⁴ to optimize the energetics of the Fontan baffle and allow for a more even distribution of hepatic blood flow to the 2 lungs. One-half of the Optiflo results in the Y-graft connection (Figure 1). The first surgical cohort of patients with the Y-graft Fontan was presented by Kanter and coworkers,⁵ who demonstrated the surgical feasibility of this novel connection. These patients with Y-grafts were treated with an off-the-shelf iliac graft (manufactured by W.L. Gore & Associates, Inc, Flagstaff, Ariz) and had similar postoperative courses to those of patients treated with the conventional total cavopulmonary connection. Postoperative flow modeling generally demonstrated a balanced distribution of inferior vena caval flow to both pulmonary arteries.⁵ In addition, Haggerty and colleagues⁶ demonstrated the similarities in the energetic performance of the Y-graft and the conventional total cavopulmonary connection by means of computational fluid dynamic studies.

"Flow simulations and validation for the first cohort of Y-graft Fontan patients" by Yang and colleagues⁷ in this issue of the *Journal* presents the simulation and validation of the first cohort of patients treated with custom-made Y-grafts, created by the surgeon in the operating room before implantation. This study also used patient-specific lung perfusion data to validate, for the first time, the hepatic

From the School of Chemical and Biomolecular Engineering,^a Georgia Institute of Technology, Atlanta, Ga; and The Wallace H. Coulter Department of Biomedical Engineering,^b Georgia Institute of Technology & Emory University, Atlanta, Ga. Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication Sept 13, 2014; accepted for publication Sept 25, 2014; available ahead of print Oct 18, 2014.

Address for reprints: Ajit P. Yoganathan, PhD, Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, Technology Enterprise Park, Suite 200, 387 Technology Circle, Atlanta, GA 30313-2412 (E-mail: ajit.yoganathan@bme.gatech.edu).

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flow distribution predictions, from an image-based computational fluid dynamic simulation paradigm of the Fontan Y-graft. With the use of magnetic resonance imaging data and the appropriate modeling assumptions, in vivo hemodynamic conditions were successfully mimicked. The agreement between the computational fluid dynamic simulation results and patient clinical data is promising. This demonstrates that image-based flow simulations can reasonably predict the complex hemodynamic environment in the Fontan Y-graft. The results presented in this article have important implications for virtual surgery planning with preoperative anatomic and hemodynamic data from patients undergoing Fontan procedures and with computational fluid dynamic simulations.

Furthermore, the study by Yang and colleagues⁷ for the first time presents 6-month postoperative follow-up data for 3 of their 6 patients receiving Fontan Y-grafts. Although the design and placement of the Y-graft can be optimized before its implantation with computational modeling with preoperative flow conditions, the anatomic and physiologic changes that occur postoperatively in these patients are not well understood and could change the vessel blood flow conditions after surgery. A surgical design planned with preoperative conditions therefore may not result in the desired hemodynamic outcomes after surgery. The data presented in this study provide preliminary insights into the time evolution of hepatic flow distribution in patients with the Fontan Y-graft, with and without pulmonary arteriovenous malformations, leading to a better understanding of the postoperative changes in hemodynamics in these patients.

Thrombosis is another important complication for patients with Fontan circulations as a whole and is not limited to patients with Y-grafts. The current study by Yang and colleagues⁷ investigated the wall shear stress (WSS) in the Y-grafts and its relationship to thrombosis. On the basis of their results, Yang and colleagues⁷ suggest that low WSS and flow stasis were likely causes for thrombus formation in 1 patient

(patient YF5 in the article). The reader should be cautioned, however, because these findings are preliminary. Thrombosis is a highly multifactorial problem that involves complex mechanical and biochemical processes. In addition, the WSS calculation in this study did not account for deformable blood vessel walls or the suture lines involved in the creation of the Y-graft. Future work should validate the WSS calculations and address how deformable walls and suture lines affect these values.

Overall, this study by Yang and colleagues⁷ is an important addition to the literature. It demonstrates the feasibility and enhances our current understanding of the Fontan Y-graft. It is a successful example of how image-based flow simulations can lead to better understanding of patient-specific hemodynamics and model potential “what if” scenarios. It also highlights the need to investigate thrombus formation phenomena in the Fontan connection and calls for more clinical data toward this end.

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