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Commentary: Yet another Fontan computational study—but this one has clay

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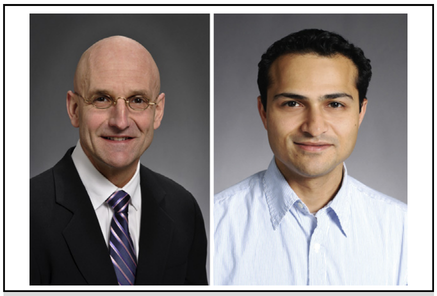

Ronald K. Woods, MD, PhD, and Salil Ginde, MD, MPH

CENTRAL MESSAGE

Surgeon-fashioned clay models may improve the efficiency of computational flow dynamics and optimization of the personalized Fontan. Optimal models require verification in reality.

What does clay have to do with computational flow dynamics (CFD) and the personalized Fontan (herein referred to as the TCPC)? Loke and colleagues' response[1] is that a surgeon-fashioned clay TCPC actually performed reasonably well and could reduce the computational time and money by serving as starting input for the CFD iterative process. With the availability of surgical modeling software, we don't fully understand the need for clay and haptic feedback but, must admit, find the use of clay kind of appealing—can't explain it, maybe it invokes pleasant childhood memories.

In contrast, I (the surgeon author) am somewhat intimidated by the implications of a personalized TCPC—that I should be capable of creating an operative field with sufficient degrees of freedom that would permit creating any TCPC the model indicates. Typically, I am working on a flaccid pulmonary artery, usually with dense adhesions behind a larger than normal neoaorta. Quite frankly, I feel fortunate if I can place an 18-mm conduit with an offset, somewhat-angulated, smooth transition to the pulmonary artery and no compression of the underlying vein. While I might be able to get close to what is specified by the model (exact location on artery, exact offset, exact angle, etc), I doubt I could get it consistently right. The impact on model-defined performance might be minimal, but it could be substantial, depending on which combination of errors I make. Moreover, the model specifies what is best at present, even though superior and inferior caval flow and native vessel diameters change with time.

I encourage anyone remotely interested in the issues of energy loss and the personalized TCPC to read the excellent review by Rijnberg and colleagues.[2] Most CFD models (3 general methods of computing energy loss) produce similar output trends but different absolute values of energy loss for a given geometry and flow condition. To date, most have made the assumption of steady flow, despite the increase of inferior caval flow with inspiration and/or exercise and with age (up to around 6 years). Models also consistently demonstrate that caval offset decreases energy loss at the expense of more uniform right/left hepatic flow distribution. Most have not accounted for the presence of systemic to pulmonary artery collateral flow, which could have a relevant contribution to resistance.[3]

Although reports vary, for most patients, the cross-sectional area of the pulmonary arteries is a more important resistive element[4]; TCPC resistance may contribute to limited exercise performance and, thus far, there is no clear association between TCPC energy loss and protein-losing enteropathy or cirrhosis of the liver. Four-dimensional flow magnetic resonance imaging overcomes many CFD assumption-related limitations. If the technology is improved to address the interrelated and competing issues of scan time, signal to noise, and spatial resolution, then 4-dimensional flow magnetic resonance imaging and CFD models with state-dependent parameters and boundary conditions could improve our

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understanding of the relative importance of energy loss in the TCPC and any relationship to longer-term outcomes.

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Commentary: A 3-minute foray into the future

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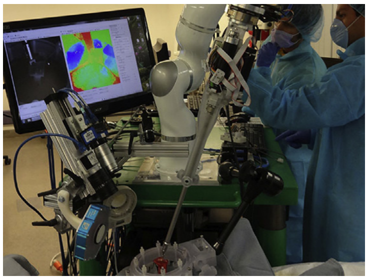
The year is 2050. Freddy Jones is about to undergo a Fontan operation. Freddy is an unusual patient. Most blastocysts are genetically screened for hypoplastic left heart syndrome, and if detected, a developing patient undergoes either embryological epigenetic modification or fetal intervention, preventing or eliminating the disorder. These techniques are still not globally available, so Freddy was not screened. Thus, Freddy is managed with the older, 3-stage palliation. In preparation for the Fontan, Freddy undergoes cardiac magnetic resonance imaging with complete pressure mapping (diagnostic catheterization became obsolete by 2030). The anatomic resolution is 50 microns. All tissue types are determined using magnetic resonance trackable biomarkers. Using controlled motions, the mechanical properties of all tissues (including connective and scar tissue) are determined. The data are then entered into a first-stage software program that builds an extracardiac Fontan circuit using computational fluid dynamics with full fluid-structure interaction (Figure 1).[1] The model incorporates a totally implantable Fontan assist



Another step has been taken toward artificial intelligence-driven surgery.

CENTRAL MESSAGE

Another advance in Fontan surgical planning may be just another step toward a future with fully automated planning and autonomous robotic surgery, as depicted in this science-fiction commentary.

mechanism. The model anatomy is adjusted in 500 iterations, using artificial intelligence to optimize approximately 50 hemodynamic characteristics under conditions of rest, exercise, and growth. The original imaging data as well as the optimized Fontan model are then input to a second stage software program that generates and stores a command sequence of robotic arm motions to be used to execute the operation from skin incision to skin closure (Figure 2). These motions are iteratively determined, using big data and artificial intelligence to optimize the combination of safety, efficiency, and accuracy of Freddy's Fontan operation. The calculations are completed in just more than 22 minutes because they are performed using a 250 petaflops (2.5×10^{17} floating point operations per second) desktop quantum computer.

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