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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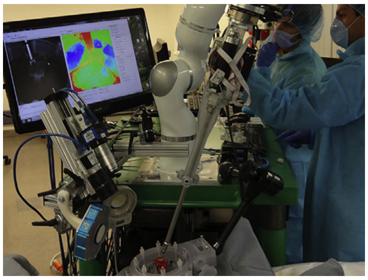

Another step has been taken toward artificial intelligence-driven surgery.

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.

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 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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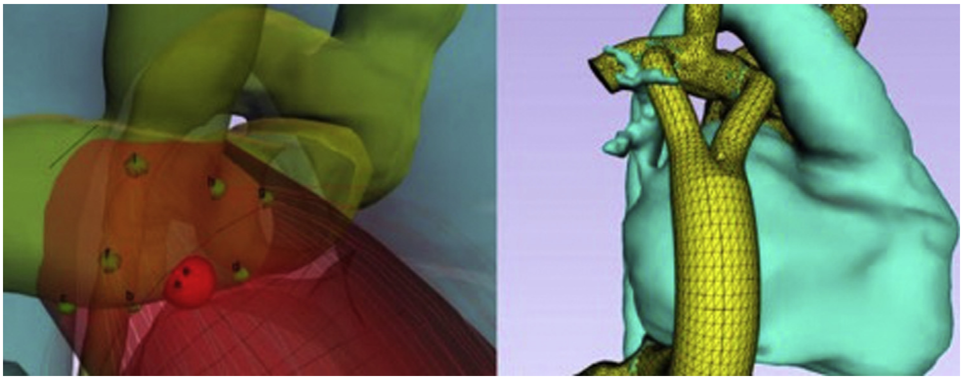

FIGURE 1. Iterative steps taken to determine optimal position of a Fontan Y-graft conduit. Image reprinted from Trusty and colleagues.[1] Used with permission.

Freddy is fortunate that early historical research introduced the principles of these techniques. For example, 30 years ago, Loke and colleagues[2] used early 21st century magnetic resonance imaging technology to collect images from 8 patients who underwent Fontan operation. Using these data, they used computational fluid dynamics software to optimize 3 hemodynamic parameters. Because computers were quite slow in 2019, they limited their optimization to 3 iterations. Additionally, they generated 3-dimensional prints of patient anatomy (a crude, transiently popular technique that preceded development and clinical application of virtual reality simulation). They then had a human being (ie, the surgeon) manually construct the Fontan circuit in the 3-dimensional print. They found that their scheme could indeed fashion a Fontan anatomy that optimized hemodynamic parameters, but the surgeon was instrumental in determining a reasonable starting model, particularly a model that optimized power loss. Although their work was limited by archaic technology, Loke and colleagues[2] contributed an important historical step in the evolution of surgical treatment for congenital heart disease.

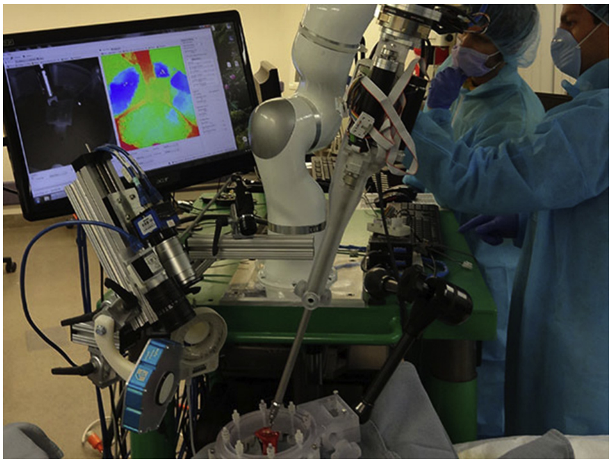

FIGURE 2. Another step has been taken toward artificial intelligence-driven surgery.

Freddy enters the operating room. His identity is checked by scanning his implanted chip. The surgeon completes a detailed checklist with the technical and clinical teams. He then presses a button to start the procedure and leaves the room. An autonomous robot has preloaded every move it will subsequently make.[3] This includes exact maneuvers to mobilize structures and retract tissue for exposure based on the preoperatively determined tissue characterization. The robot has 8 arms, each with 4 joints and 9 degrees of freedom. It is the only entity at the operating table, working with great precision (40-micron spatial resolution) and impressive speed and efficiency. On weaning bypass, the Fontan pressure at the inferior vena cava is 7 mm Hg. The operation is complete in 47 minutes. The robot prints its report, and the surgeon re-enters the room to co-sign it. Freddy recovers well.

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