

Case Study



TAILORING TREATMENT TO THE INDIVIDUAL PATIENT

Simulation helps clinicians choose the best option for a successful artery repair

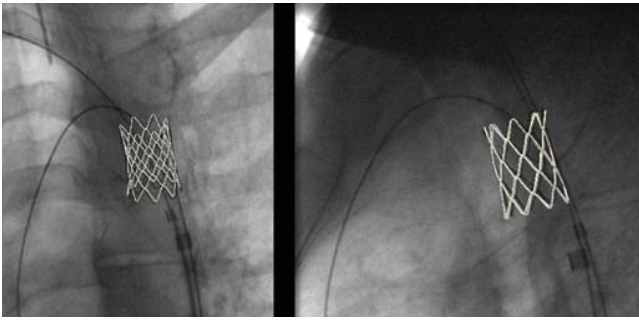
The 19-year old patient was in trouble. Born with an initially undetected congenital malformation of the aorta, the major artery of the heart, he had a metal stent implanted at eight years of age to widen the blood vessel and restore normal flow. At first the treatment to correct his coarctation of the aorta (COA) was a success. But, despite re-dilation six years later, the supporting structure of the stent narrowed again, fracturing in places and allowing the aorta to form a small but potentially dangerous aneurysm (a bulge in the vessel wall that could burst).

Many types of congenital heart abnormalities can be corrected in very young babies through open-heart surgery. But sometimes such problems aren't identified until a person is older. Even repairs made at birth can occasionally fail over time. Balloon angioplasty—the insertion via catheter, of an inflatable balloon that widens the blood vessel—became an accepted (and much less invasive) corrective procedure in the 1980s for older children or adults. Starting in the 1990s, adding a stent into a balloon-widened artery (as was done with this patient when he was eight) proved to be an effective way to stave off further complications.

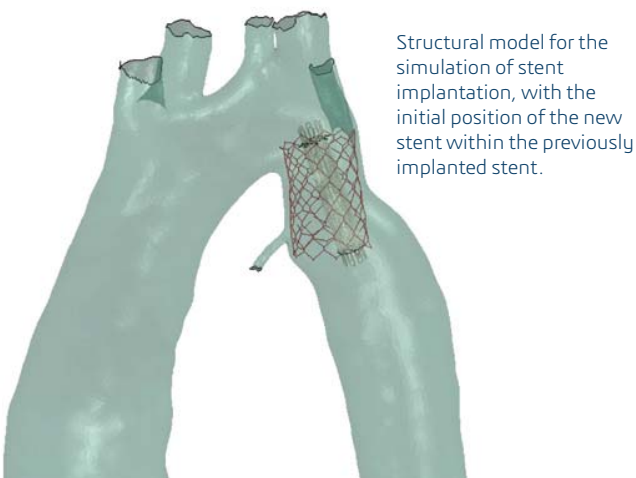
But doctors who were monitoring this patient's condition realized by the time he was 18 that complications had, in fact, developed. An echocardiogram and examination through a catheter-guided system revealed that the COA had recurred and was now accompanied by a threatening aneurysm. A covered stent is usually placed to protect the aneurysm, but in this patient, another important artery bringing blood to the right arm was starting from the site of implantation and could not be risked. As the patient turned 19, the cardiologists began planning to replace the defective stent and repair the blood vessel wall in order to keep the young man healthy. But what would be the best route to success?

SIMULATION HELPS ENGINEERS AND CLINICIANS COLLABORATE

Modern body-scanning technologies clearly show that no two people's anatomies are alike. Fortunately, this individuality can now be translated into patient-specific computational modeling, which is becoming a powerful, recognized tool to help clinicians plan complex interventions. Although not widely employed for treatment planning yet, use of such



Overlay of the simulated stent (white) onto the procedural fluoroscopy images (front and lateral) of the patient post-implantation. The guidewires and delivery catheter are still in place.



Structural model for the simulation of stent implantation, with the initial position of the new stent within the previously implanted stent.

simulation methodology is starting to produce real-world results as engineers and physicians increasingly collaborate on patient cases.

Researchers from Clinical Cardiovascular Engineering at University College London Institute of Cardiovascular Science had the capabilities to help the young patient and his doctors at Great Ormond Street Hospital for Children. Embedded in the hospital's cardiology department, they have expertise in computer simulation that helps bring the power of virtual problem solving to real-life patient cases. In addition to Abaqus finite element analysis (FEA) from Dassault Systèmes' SIMULIA, their toolkit includes computational fluid dynamics (CFD), and image post-processing software.

MODELING THE PATIENT'S CHALLENGES

"In order to create computer models that accurately reflected this patient's condition, we needed to start from his unique geometric data," says Silvia Schievano, Ph.D., researcher at UCL. The shape details and anatomical relationship between the different structures was captured by a computed tomography (CT) scan. Magnetic resonance imaging (MRI) provided a way to visualize the current haemodynamics (blood flow), with two-dimensional phase-contrast images taken to assess flow measurements of the ascending and descending aortas and all the associated smaller arteries.

Next the CT images were used to create in silico patient-specific 3D geometry, and flows and velocities were extracted from the MRI data. Catheterization angiograms coupled with echocardiographic measurements were used to guide plans for reconstructing the narrowed (stenotic) site.

With structural and CFD working models of the patient's current condition in hand, the team could now simulate the insertion of different sizes of a replacement stent (a CP™ covered one from NuMED) into the aorta, and predict the effects of each one on blood flow and pressure—with the goal of identifying which would be best to recommend to the young man's doctors.

CHOOSING THE RIGHT SIZE STENT MAKES ALL THE DIFFERENCE

Four virtual stents were virtually tested in the patient geometry—14, 16, 18 and 20 mm. The simulations revealed that the 14 mm device didn't completely contact the interior walls of the blood vessel. The 20 mm stent obstructed part of the origin of the arm artery. The 16 and 18 mm stents showed safe anchoring to the arterial wall, no obstruction of the arm artery and protective coverage of the aneurysm as well. The researchers suggested to the patient's cardiologist that either the 16 or 18 mm diameter stents would work well.

The procedure was successfully carried out with a 16 mm diameter stent. Follow-up angiograms of the patient showed that the blood flow was restored, the aneurysm was excluded and that the aberrant portion of the artery was functioning well.

"The overall results of the recommended procedure were well predicted by the FEA and CFD analyses we performed in advance," says Research Associate, Claudio Capelli, Ph.D. "Our modeling techniques provided important supplemental information to the clinicians that improved their confidence in the treatment."

VIRTUAL TREATMENT PLANNING PRODUCES BETTER OUTCOMES, COST-EFFECTIVELY

"Finite-element models such as this allow inexpensive testing of different scenarios within a virtual reality that can realistically replicate an individual patient's condition," he says. "Not only could everyone involved visualize the predicted results together, the clinicians could also use the numerical data generated by the simulation to compare different strategies for providing safe anchoring and aneurysm treatment."

"When engineers and physicians collaborate like this, through the use of simulation to provide personalized medicine, patients could truly benefit by informed decision making and more efficient treatment," says Schievano.

The patient in this example is now 23 years old and doing well.

For More Information

www.ucl.ac.uk/cardiac-engineering