Coronary artery disease — which is the blockage of arteries that provide blood to the heart — is the leading cause of death in the world today. The World Health Organization notes that around 30 percent of all deaths worldwide are due to cardiovascular disease. [1] Occurrences of this disease are increasing both in numbers and in geographic range, making the development of new diagnosis and treatment options critical.

Thirty percent of all deaths worldwide in 2008 were due to some form of cardiovascular disease.
Clinical cardiologists and simulation experts at the VIRTUheart™ project at the University of Sheffield in the United Kingdom are using ANSYS computational fluid dynamics (CFD) simulation to improve diagnosis of the severity of coronary artery disease in a given patient. Non-invasive modeling of the pressure drop across a lesion (blockage) gives clinical cardiologists a quantitative metric to help them decide whether to perform invasive procedures — insertion of stents or cardiac bypass surgery — or to simply medicate those patients with less severe conditions.

Reducing discomfort, invasiveness and risk, as well as increasing successful treatment outcomes, is of obvious value to patients. The potential monetary savings involved in simplifying the procedure, performing fewer stent procedures, and avoiding costly bypass surgeries are enormous to a world increasingly overwhelmed by healthcare costs.

TO TREAT OR NOT TO TREAT?

When a patient arrives at a cardiac catheterization laboratory complaining of chest pain, an angiogram is performed to get an anatomical picture of the coronary arteries. A constriction in an artery indicates a lesion. Two questions arise: How bad is the constriction, and what action should be taken?

The decision is a subjective one, dependent on the experience and judgment of the cardiologist. Ask several cardiologists for their assessment of the same lesion and you are likely to get several different opinions. A decision is needed quickly.

Physiological data — as opposed to the purely anatomical data shown in an angiogram — can be obtained by inserting a wire outfitted with a small pressure sensor into the artery in question and measuring the pressure on both sides of the lesion. The pressure drop across the lesion reveals the severity of the blockage. Dividing the lower pressure by the higher pressure yields a number between 0 and 1 that is known as the fractional flow reserve (FFR). If the FFR is above 0.80, the narrowing is unlikely to cause any clinical symptoms or problems. Values below 0.80 mean that blood flow can become restricted. A high FFR is good news for the patient, while patients with FFR values far below 0.80 are clear candidates for either stent insertion or cardiac bypass surgery. The tough decisions come when the FFR is close to the 0.80 threshold point.

Clearly, the measured FFR value (mFFR) derived from this technique gives the cardiologist an objective value to help in making treatment decisions, placing less reliance on the doctor’s subjective judgment based on experience. Unfortunately, the pressure measurement procedure to obtain the mFFR value is performed in less than 10 percent of cases in which stents are inserted in the U.K. Because the procedure involves inserting a wire inside an artery, it adds expense and prolongs patient discomfort, so, although the pressure measurement procedure offers significant advantages, doctors around the world have not adopted this invasive technique in high percentages.

DETERMINING FFR VIRTUALLY

ANSYS solutions are used extensively at the INSIGNEO Institute for

Cardiologists and simulation experts at VIRTUheart are using ANSYS CFD to accelerate and improve diagnosis of the severity of coronary artery disease in a given patient.
In Silico Medicine at the University of Sheffield, so it was natural to turn to modeling and simulation of the coronary arteries to try to obtain a virtual, non-invasive FFR value (vFFR™). Such a solution, researchers hoped, would clear the way for higher adoption of this valuable measure in coronary treatment decisions. The potential benefit in improved patient outcomes was the driving force for this investigation.

Researchers conducted a pilot study involving 19 patients with stable coronary artery disease and a total of 35 constricted arteries using ANSYS CFD. [2] They obtained rotational coronary angiograms to give a 3-D picture of the coronary vessels. (Additional investigation following this clinical trial has been done to eliminate the need for rotational coronary angiography, as this instrumentation is less commonly available than standard 2-D angiography instrumentation. Results of this research are not yet available.) The team segmented the angiograms to produce 3-D arterial geometries. Customized software created a surface mesh and volumetric mesh comprising approximately 1.5 million cells. Researchers applied generic pressure and flow boundary conditions, as opposed to patient-specific ones, to the model. They then imported the meshed geometry into ANSYS CFX for CFD simulation of the pressure drop across the lesions and calculation of the vFFR.

The mFFR and vFFR values obtained for the pilot study were in good agreement. The overall diagnostic accuracy of vFFR was 97 percent. A plot of vFFR versus mFFR had a correlation coefficient of 0.84.

ADVANTAGES OF vFFR

Having the ability to determine FFR virtually should eventually lead to greater adoption of this valuable physiological parameter in determining the appropriate treatment for an arterial lesion. The vFFR method requires only angiogram images and CFD simulation — no invasive insertion of wires with pressure sensors into the patient’s arteries. On this basis alone, vFFR could have a huge positive effect on patient outcomes and monetary healthcare savings.

In addition, vFFR provides a pressure profile of the complete arterial system being modeled, which is a great improvement over the single-point pressure drop value that the mFFR method yields. The distribution of pressures in the CFD simulation clearly shows the regions where pressures change the
most. Such comprehensive detail is not available from mFFR, which provides only a single-point pressure measurement.

In cases in which two or three lesions are present in a single coronary artery, the lesions function as part of a system. Cardiologists might be inclined to stent every lesion. However, stenting the first upstream lesion may improve the pressure conditions such that the downstream lesions do not require a stent.

The researchers at VIRTUheart are currently working on extensions to the model that will make virtual stenting possible. For example, the cardiologist might eventually be able to insert stents virtually into the model and see what effect this stent might have on the other lesions and arteries in the system. Being able to preview a treatment in silico before trying it in a human patient should lead to better outcomes and save money by reducing the number of implanted stents.

Even though the pilot study showed that vFFR had a very high diagnostic accuracy of 97 percent, there is room for improvement. The initial study was performed with generic boundary conditions for blood pressure and flow. VIRTUheart researchers are investigating how the use of patient-specific boundary conditions could improve diagnostic accuracy of vFFR even more.

Ultimately, the decision about how to treat a cardiovascular lesion can be a determining factor in patient lifespan and quality of life. The decision to opt for cardiac bypass surgery, perform stent insertion or simply treat with medication can make a big difference. If you are the person lying on the table in the cardiac catheterization laboratory, you want your doctor to have all the best data possible to make his or her treatment decision. VIRTUheart and ANSYS are working together to help your doctor make the best decision for you.

References

▲ Meshing applied to coronary artery prior to simulation