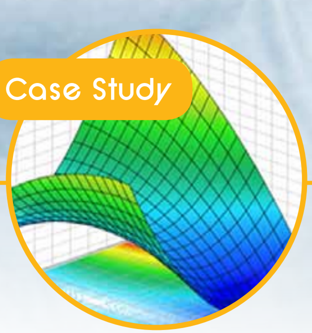
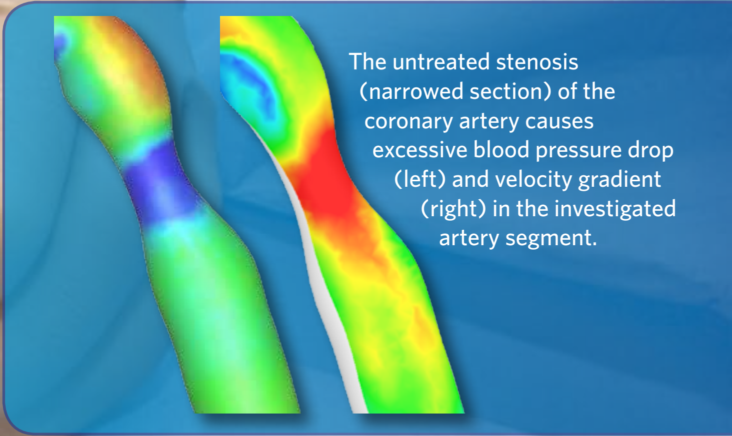
Design for real

Optimus®

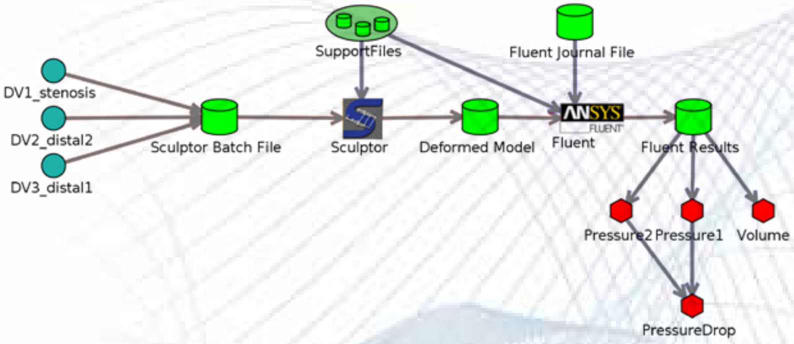




The untreated stenosis (narrowed section) of the coronary artery causes excessive blood pressure drop (left) and velocity gradient (right) in the investigated artery segment.

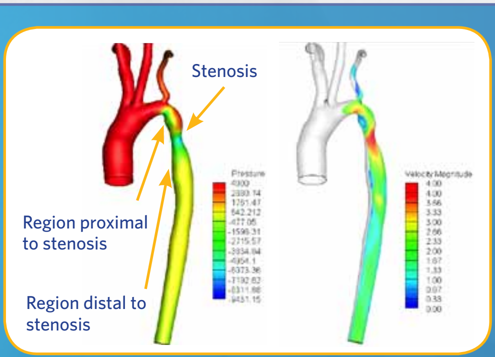
Optimus-driven CFD optimization makes a case for patient-specific coronary stents

When cardiologists treat narrowed or blocked heart arteries as found in coronary heart diseases, they typically use off-the-shelf available stents. Placing such stents permanently opens the arteries at locations with build-up of cholesterol-laden plaques. Engineering simulation plays little or no role in this process. Recent research resulted in an Optimus-managed simulation process that optimizes medical intervention for improving local coronary blood circulation. In this optimization process, Optimus integrates mesh morphing (using Sculptor) and computational fluid dynamics (CFD) simulations (using ANSYS Fluent) into an automated, repeatable process. Optimization results underline the need for patient-specific stents that optimize local blood circulation for heart disease patients undergoing medical treatment. Compared to treatment using standard coronary stents, optimized patient-specific stents were found to improve local blood circulation characteristics by over 20%.

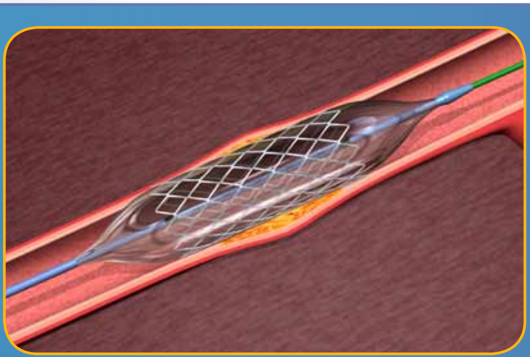


noesis
Empower your experience

Simulation & optimization to improve heart disease treatment



CFD simulation is applied to assess the complex fluid dynamics induced by the stenosis (narrowed section of the artery) in its proximal (upstream) and distal (downstream) regions.



Using a catheter fed through blood vessels, a balloon is inflated and a commercially available stent inserted to permanently open the narrowing artery.

Coronary heart disease treatment

In the USA, over 600,000 persons died from heart disease last year alone. Coronary heart disease is the narrowing or blockage of the coronary arteries, usually caused by hardening or clogging of the arteries. It is a condition in which an artery wall thickens as a result of the accumulation of fatty materials such as cholesterol. A frequently applied treatment is percutaneous coronary intervention (PCI), which is performed by a cardiologist.

Cardiologists use computational axial tomography (CAT) scans with radio-opaque contrast in the coronary arteries, as an aid to diagnose heart disease and assist during PCI treatment. Using a catheter fed through blood vessels, a balloon is inflated at the site of blockage to open the artery and allow the blood to flow. Often, a commercially available stent is inserted at that location to permanently open narrowing or blocked arteries by imposing a specific artery diameter.

Improving blood circulation

In a project conducted with the Riverview Medical Center (Indianapolis, IN) medical researchers are studying the impact of stents on blood flow characteristics. As part of their research, they collaborate with CFD engineers to investigate innovative ways to further improve blood circulation. CFD experience is critical to correctly model the complex fluid dynamics induced by the stenosis (narrowed section of the artery) in its proximal (upstream) and distal (downstream) regions. The CFD engineers then use Optimus to automate the CFD analyses over a longer segment of the narrowed artery, and to direct simulations towards an optimized solution.

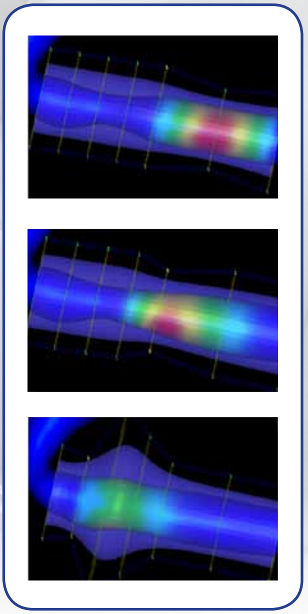
CFD-based artery optimization

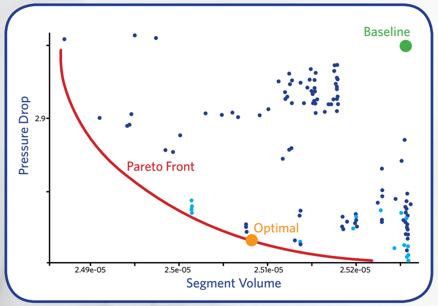
The engineering team started from the medical imaging data of a patient who had received treatment on the stenosis of the aorta, the largest artery in the human body. They selected this particular patient casus, because the CAT scan was readily available and the aorta exhibits the same hemodynamic properties as the coronary arteries further downstream. Based on the CAT scan data, the engineers created the original CFD mesh model with ANSYS ICEM CFD.

The initial CFD model of the aorta segment contained the untreated stenosis along with its proximal and distal regions. The CFD engineers used ANSYS Fluent to simulate the complex fluid dynamics, and set up, automated and directed the CFD simulation process using Optimus. This enabled them to run a parametric CFD simulation campaign in order to assess the blood flow improvement margin and identify an optimized artery shape. The team's goal was to compare the CFD results of the optimized virtual artery (delivered by the parametric simulation campaign) with the CFD characteristics of the real artery (treated using a standard coronary stent).

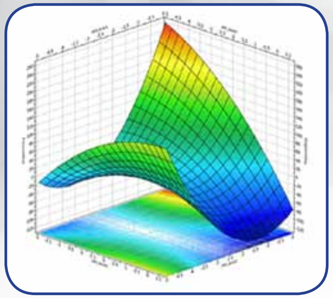
Improving blood pressure drop and medial velocity over 20%

The three design parameters are groups of Sculptor control points that deform the artery shape. One group deforms the geometry at the distal region, another at the stenosis region, and a third at the proximal region.





Optimus' multi-objective evolutionary algorithms revealed a shallow Pareto front, representing optimized artery shapes that deliver a trade-off between both competing design objectives.



An RSM displaying the pressure drop (color and elevation) in relation to the design variables morphing the distal region of the geometry.

Speeding up simulation tenfold

To avoid a complete re-calculation with each new CFD model, the engineers decided to use mesh morphing technologies to repeatedly adapt the CFD model. Mesh morphing removes the need to re-mesh the CFD model with each new simulation, and avoids a costly recalculation of the physics equations with every new CFD model. Combined with Optimus' capability to submit simulation jobs in parallel over the available hardware infrastructure, this approach reduces total elapsed time of the simulation campaign by a factor of 10.

Deciding on design parameters

The engineers decided to use Sculptor for its real-time mesh-morphing capabilities. Sculptor uses Bezier volumes to morph the nodes of the artery mesh, without any node renumbering or element swapping. The three design parameters are groups of Sculptor control points that deform the artery shape.

Assessing blood circulation improvement potential

The Latin Hypercube method was applied to define 16 well-chosen virtual experiments to sample the design space most effectively. From the results, a response surface model (RSM) was created using a Taylor's Series Least Squares method. This surrogate model condenses the complex fluid simulations to help the CFD engineers grasp the blood circulation improvement potential early in the process.

Setting the optimization objectives

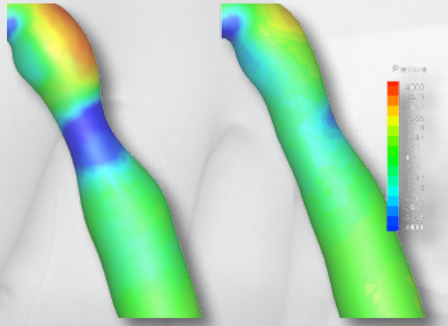
As the first objective, the engineers wanted to minimize the pressure drop across the start and end cross section planes of the entire artery segment considered during the simulations. This established a favorable situation that avoids excessive velocity gradients at the medial area (stenosis). Secondly, they aimed at minimizing the total volume of the mesh to avoid expansion of the proximal region. Any expansion to this region would indicate weak arterial walls. Both objectives were competing, as is often the case in design optimization projects.

Better results with optimized stents

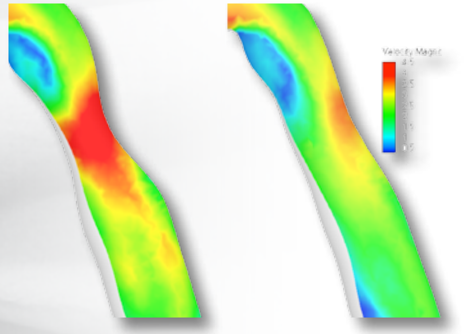
The optimization process driven by Optimus' non-dominated sorting evolutionary algorithm (NSEA) progressively reduced the velocity gradient at the stenosis and the pressure on the distal region, revealing a shallow Pareto front. Points on this front represent feasible artery shapes offering the most favorable trade-offs between both competing design objectives.

The optimal artery shape identified by Optimus reduced the blood pressure drop across the artery segment by 28%, compared to the patient's PCI treatment. At the same time, Optimus reduced the hemodynamic flow velocity through the medial area (stenosis) by 22%. The volume of the artery remained the same, because the volume reduction in the distal region compensates for the widening of the medial area.

As an alternative to PCI treatment using standard stents, Optimus identifies the geometry of patient-specific coronary stents that improve local blood circulation by over 20%.



The optimal artery shape identified by Optimus reduced the blood pressure drop across the artery segment by 28%, compared to the patient's PCI treatment.



At the same time, Optimus drastically reduced the blood flow variability. The hemodynamic flow velocity through the medial area (stenosis) decreased 22%.

Process optimization

☑ **Easily integrate multiple software tools into a single simulation campaign**
Engineers set up the simulation workflow in Optimus' graphic process editor, covering the entire process of mesh morphing and computational fluid dynamics.

☑ **Reduce elapsed time of the entire simulation campaign**
Optimus drives mesh morphing and submits CFD simulation jobs in parallel over the available hardware infrastructure, speeding up the simulation campaign by a factor of 10.

☑ **Automate the simulation-based design process**
Optimus directs the automated simulation campaign to deliver the optimum artery shape starting from the optimization objectives defined up-front, eliminating manual data processing.

Design optimization

☑ **Gather maximum design space intelligence**
Optimus' surrogate modeling capabilities condense the complex fluid simulations to help CFD engineers grasp the blood circulation improvement potential early in the process.

☑ **Direct the optimization process toward the best possible artery shape**
Optimus' evolutionary optimization algorithms balance both conflicting optimization objectives, reducing the pressure drop across the investigated artery segment by 28% while simultaneously minimizing its total volume.

☑ **Stretch the limits of medical interventions**
Blood circulation results beyond what cardiologists achieve using standard coronary stents, make a case for patient-specific stents.

Noesis Solutions NV
Gaston Geenslaan, 11 B4
3001 Leuven – Belgium
Phone +32 (0)16 317 040
Fax +32 (0)16 317 048
info@noesissolutions.com

www.noesissolutions.com

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