Battle of the Bulge

Rapid prototyping results in a new surgical tool to treat back pain.

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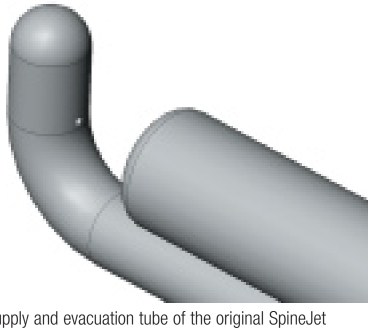
In the United States, back pain is one of the most common reasons for healthcare visits and missed work. Four out of five adults have at least one bout of back pain at some point in their lives.

A common source of pain is from a bulging intervertebral disc impinging on spinal nerves, which can cause back pain or sciatica (pain down the leg) — a condition known as herniated disc. The intervertebral disc is sandwiched between the vertebrae of the back and acts as a shock absorber during spinal movement. The disc is made of two parts: a tough outer wall called the annulus and a gelatinous inner core called the nucleus. Trauma or aging of the disc can cause the annulus to bulge.

Most occurrences of lower back pain resolve with rest and medication. For many people, though, the pain can be debilitating and last for several months to years. Such patients typically require surgery.

Minimally invasive surgical techniques offer many benefits, since traditional back surgery can cause further pain and complications. HydroCision, which develops and manufactures fluidjet-based surgical tools in the United States, used computational fluid dynamics (CFD) to improve a novel minimally invasive surgical treatment called HydroDiscectomy™.

The goal of HydroDiscectomy is to decompress the herniated disc. When performing the procedure, a physician uses a tool called the SpineJet® to remove a portion of nucleus, which debulks the disc and retracts the bulge. The device uses a high-pressure jet of sterile water directed into an evacuation tube. The jet is attuned to cut the softer nucleus but protect harder surrounding tissues such as the vertebrae and the annulus. The water jet naturally provides cutting and a low-pressure Venturi to draw the nucleus to the jet, cut it and aspirate it through an evacuation tube.



Supply and evacuation tube of the original SpineJet
Image courtesy T.G. Communications.

The SpineJet repairs a herniated intervertebral disc by removing a portion of the nucleus. The tool uses the Venturi effect created by high-velocity saline jets to cut and then aspirate targeted tissue. Image courtesy T.G. Communications.

As physicians adopt new technologies, their product demands increase. HydroCision saw CFD as a technology that could reduce development time and improve product performance. Manufacturing limitations with the existing SpineJet nozzle affected the flow divergence, directionality and alignment with the evacuation tube. By redesigning the SpineJet nozzle for better flow characteristics and greater ease of manufacture, the surgical device could be made more consistent and cost-effective. HydroCision's product development team used FLUENT software in analyzing the performance of the existing nozzle geometry. CFD simulations allowed new geometries to be designed and analyzed for performance in a matter of hours to days. Optimization of the device was faster and less expensive than the traditional method of making and testing prototypes.

The CFD model included flow simulations through the supply tube, nozzle orifice and evacuation region. CFD results helped the HydroCision team visualize critical flow characteristics such as the velocity profile, pressure distribution and flow divergence (cone angle).

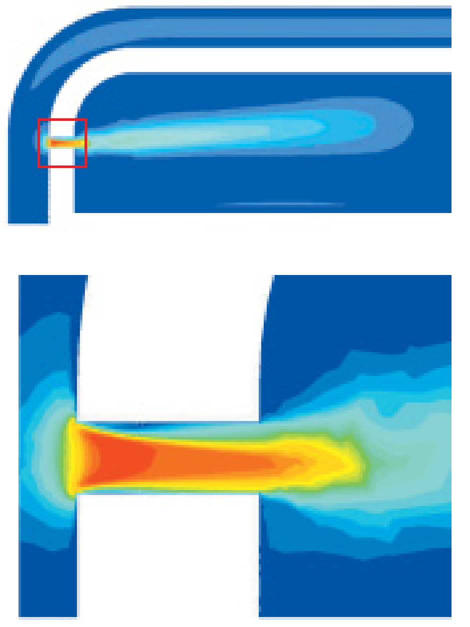
The team modeled six alternate SpineJet designs that incorporated significant changes to the nozzle and/or the supply tube. Engineers selected velocity magnitude and general jet shape as the primary means for comparing the different designs, since these two parameters are considered the most accurate predictors of overall SpineJet performance.

CFD results for the existing SpineJet showed the influence of a sharp-edge orifice and its location on the flow characteristic. As expected, the orifice creates a flow separation at the corner, and a vena contracta is formed. In addition, the proximity of the orifice to the 90-degree-bend in the supply tube and the additional supply tube length past the orifice create a non-uniform flow condition at the orifice entrance. As a result, the region of highest flow velocity is concentrated in the lower portion of the orifice; therefore, the flow is neither symmetrical nor well developed.

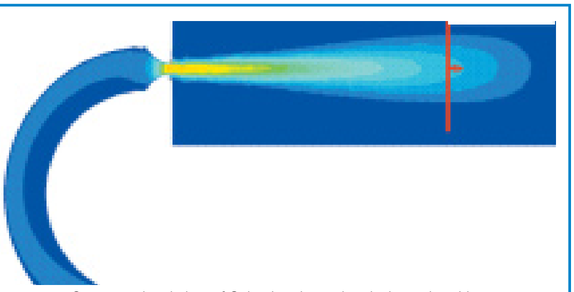
CFD results for the alternate SpineJet designs showed substantial improvement compared to the existing design. Three of the alternate configurations had 20 percent higher mass flow rates than the existing design as well as a 40 percent reduction in cone angle (flow divergence). These designs had general jet shapes that were symmetrical and well developed. They also retained higher flow velocities over longer distances from the orifice exit.

Historically, HydroCision manufactured prototypes of new geometries for testing to examine the feasibility of producing a new and improved design. Although fairly effective, this method was costly (more than $15,000 for each design tested) and time-consuming (taking approximately six months). Furthermore, testing did not always lead to a full understanding of the fluid flow characteristics that occur.

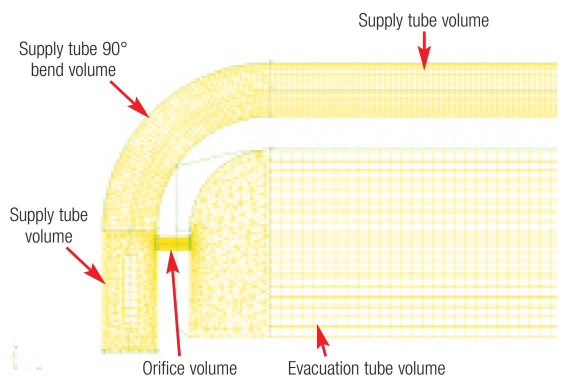
Computer modeling utilizing FLUENT software provides a different approach to the problem. The only expenses are computing and software costs; creating a CFD model and running it takes just a few days. This allows HydroCision to model and refine many designs in a fraction of the time it would take to manufacture and test a single prototype. In addition, computer simulation can yield better insights into the interactions between the geometry and the fluid flow. Finally, the graphics generated by FLUENT software help stakeholders better understand the operation of the surgical tool. ■



Cross-sectional view of all fluid volumes for original SpineJet design (top) with close-up section indicated by the red box at orifice (bottom)



Cross-sectional view of SpineJet alternative design colored by velocity magnitude



Cross-sectional view of all fluid volumes

About the Industry Spotlight

Cover image: Simulation demonstrates shape memory for a cochlear implant. Photo courtesy Cochlear GmbH. Simulation courtesy Fachhochschule Hannover – University of Applied Sciences and Arts, CADFEM GmbH and Dr. Omid Majdani – Hannover Medical School.

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