Ventricular catheter obstruction

One of the leading causes of CSF shunt failure is obstruction of the ventricular catheter by aggregations of cells, proteins, blood clots, or fronds of choroid plexus that occlude the catheter's small inlet holes or even the full internal catheter lumen. Such obstructions can disrupt CSF diversion out of the ventricular system or impede it entirely. Previous studies have suggested that altering the catheter's fluid dynamics may help to reduce the likelihood of complete ventricular catheter failure caused by obstruction. However, systematic correlation between a ventricular catheter's design parameters and its performance, specifically its likelihood to become occluded, still remains unknown. Therefore, an automated, open-source computational fluid dynamics (CFD) simulation framework was developed for use in the medical community to determine optimized ventricular catheter designs and to rapidly explore parameter influence for a given flow objective. METHODS The computational framework was developed by coupling a 3D CFD solver and an iterative optimization algorithm and was implemented in a high-performance computing environment. The capabilities of the framework were demonstrated by computing an optimized ventricular catheter design that provides uniform flow rates through the catheter's inlet holes, a common design objective in the literature. The baseline computational model was validated using 3D nuclear imaging to provide flow velocities at the inlet holes and through the catheter. RESULTS The optimized catheter design achieved through use of the automated simulation framework improved significantly on previous attempts to reach a uniform inlet flow rate distribution using the standard catheter hole configuration as a baseline. While the standard ventricular catheter design featuring uniform inlet hole diameters and hole spacing has a standard deviation of 14.27% for the inlet flow rates, the optimized design has a standard deviation of 0.30%. CONCLUSIONS This customizable framework, paired with high-performance computing, provides a rapid method of design testing to solve complex flow problems. While a relatively simplified ventricular catheter model was used to demonstrate the framework, the computational approach is applicable to any baseline catheter model, and it is easily adapted to optimize catheters for the unique needs of different patients as well as for other fluid-based medical devices [1).

May account for 50-80 % of newly inserted shunts. Although many factors contribute to this, the main one is related to flow characteristics of the catheter within the hydrocephalic brain. A landmark study by Lin et al. addressed the problem of fluid characteristics in ventricular catheters using a two-dimensional simulation program of computational fluid dynamics (CFD).

Most commercially available ventricular catheters have an abnormally increase flow distribution pattern. New catheter designs with variable hole diameters along the catheter tip will allow the fluid to enter the catheter more uniformly along its length, thereby reducing the probability of its becoming occluded [2).

Despite ongoing research into better shunt design, robust and reliable detection of shunt malfunction remains elusive. The authors present a novel method of correlating degree of tissue ingrowth into ventricular CSF drainage catheters with internal electrical impedance. The impedance based sensor is able to continuously monitor shunt patency using intraluminal electrodes. Prototype obstruction sensors were fabricated for in-vitro analysis of cellular ingrowth into a shunt under static and dynamic flow conditions. Primary astrocyte cell lines and C6 glioma cells were allowed to proliferate up to 7 days within a shunt catheter and the impedance waveform was observed. During cell ingrowth a significant change in the peak-to-peak voltage signal as well as the root-mean-square voltage level was observed, allowing the impedance sensor to potentially anticipate shunt malfunction long before it affects fluid drainage. Finite element modeling was employed to demonstrate that the electrical signal used to monitor tissue ingrowth is contained inside the catheter lumen and does not endanger tissue surrounding the shunt. These results may herald the development of “next generation” shunt technology that allows prediction of malfunction before it affects patient outcome [3].

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