"Intracranial Hemorrhage Model" - Design Excellence Award - Executive Summary

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Intracerebral hemorrhage (ICH) is a devastating form of 10-15% of stroke which affects over 100,000 people in the USA each year. A sudden release of blood into the parenchyma of the brain tissue causes immediate tissue damage, increased intracranial pressure, and a loss of neurological function. Over time the blood forms a fibrous clot settled within a pool of plasma. This detrimental process can only be mediated by removal of the clot volume as soon as possible after the initial stroke onset. Due to the delicate nature of brain tissue, there are few options available to ICH patients. Current experimental treatments rely on Computed Tomography (CT) and Ultrasound to place a catheter in the hemorrhaged clot, at which point a clot lysing (or breakdown) agent is administered. The clot is broken from a solid, fibrous material into a liquid which can be easily drained to reduce intracranial pressure. CT and Ultrasound are well established medical imaging technologies, however they fail to identify characteristics of the clot which could speed up treatment time, critically limiting patient outcomes. The underlying hypothesis of the project is that the use of Magnetic Resonance Imaging (MRI) as the primary imaging modality will allow a surgeon to discern between fibrous and plasma portions of the clot, thereby appropriately administering a lysing agent for maximum breakdown of the clot. In order to validate this theory, a brain model which appears similar to clinical ICH under MRI and exhibits dynamic behavior is required prove functionality of clot lysis within a MR environment before proceeding to human subjects.

It is important to note that ICH treatment with MRI is a novel technique and we are the first to attempt creation of a model to validate this theory. There are many established models for mimicking properties of brain tissue, such as tensile strength or flexibility. However, these models do not behave dynamically as the brain does. Our model must adjust to the changing environment as a clot is lysed and drained. The team initially decided that mimicking the physiological properties of the brain, such as pressure, temperature and mechanical properties, was crucial to the model behavior. However, these characteristics were set aside once the team realized that only the imaging capability under MR is relevant. A separate concern was that operating the model at room temperature instead of body temperature would alter the functionality of the lysing agent. Further research concluded that the room temperature would not significantly decrease the capabilities of the agent. With these realizations, the team built a simple and effective brain model comprising of an exterior shell containing a layer of agarose with an embedded clot, and a surface hydrogel layer. The exterior shell has multiple ports for catheter insertion, simulating the surgeon's need to access the clot from the most effective direction. An agarose base containing the clot provides a stable location for the clot to settle. In the brain, the clot does not move around so it was essential to mimic this in our model. Low density polyethylene was the chosen to serve as the clot membrane to allow catheters to penetrate the clot without leaking into the surrounding hydrogel. This membrane was essential to maintain a clinically effective concentration of the clot lysing agent as well as to avoid wasting the costly lysing agent into the hydrogel. Finally, hydrogel was chosen as the material surrounding the clot since it is able to reconfigure itself in a direct response to the void created as the clot drains.

The team conducted several rounds of validation testing. The clots modeled were biphasic, consisting of two materials to simulate both plasma and fibrous clot in actual hemorrhage. The first model was tested with a clot consisting of water and oil under MRI, with only the water portion being drained. This primitive clot allowed the team to display that the model could function by allowing draining distinctly separate portions of the clot. With this test it was also evident that the model created images similar to that of clinical ICH MR images. Success of this test indicated the model was ready to be tested with an actual clot consisting of the fibrous and liquid phases of animal blood. Upon completion of testing with animal blood, it is clear that the model is effective in providing a platform on which to test clot lysis and drainage visualized under MRI. The team has successfully shown that the model behaves similarly to the brain as the hydrogel flows in to fill the void space formed by the clot drainage. Secondly, the model yields MR images similar to clinical ICH scans. Equipped with this model as a platform, researchers will be able to produce reference images of clot behavior and lysis to customize treatment and improve patient outcomes.