3D Computational Modeling of Cerebral Artery
Network During Therapeutic Hypothermia Enhanced
Thrombectomy Procedures - Problem Statement

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Introduction and Background:

Stroke is caused by an interruption of brain blood supply. It is one of the leading causes of death
and disability in the world today. While the brain makes up only 2% of the total body mass, it
requires 15% of the body’s blood supply\(^1,2\). According to the World Health Organization in 2011,
stroke and other cerebrovascular diseases were the number two leading cause of death worldwide\(^3\).
It accounted for over 10.8% of deaths worldwide, while many survivors will suffer permanent
disabilities.

In cases of ischemic stroke, which accounts for 87% of all strokes\(^4\), the interruption is com-
monly caused by a blockage in the major arteries shown in Figure 1, causing surrounding brain
tissue death. A hemorrhagic stroke which accounts for 13% of strokes is caused by a weakened
blood vessel that ruptures and bleeds into brain tissue, resulting in brain compression. Our pro-
posed research will focus on ischemic related stroke and modeling.
Figure 1: Overhead view of head showing a typical Circle of Willis structure and corresponding fluoroscopy scan. The internal carotid artery (ICA) and middle cerebral artery (MCA) are common sites of blockage.

Therapeutic hypothermia (TH) is a new treatment that reduces a patient’s temperature to induce mild to moderate levels of hypothermia (2-5°C reduction in core temperature) throughout the entire body or at specific organs. The objective of TH is a reduction or elimination of reperfusion injury associated with re-establishing blood flow to an ischemic organ. Therapeutic hypothermia has already proven benefits in the applications of cardiac arrest in numerous research journals and clinical studies. In a study of coma patients who suffered cardiac arrest, Bernard et al. found 49% of hypothermia patients, having a core temperature of 33°C from external cooling, had an improved outcome of reduced tissue damage. While only 26% in the non-hypothermia group had a similar outcome. In 2005 Holzer et al. conducted a randomized trial of 275 adults to determine the neurological effects of TH following cardiac arrest. The results showed a favorable outcome to 55% of patients in the hypothermia group compared to 39% in the non-hypothermia group; six-month mortality rates were also 14% lower in the hypothermia group.

Results from a meta-analysis of 101 ischemic stroke publications, which included 3353 animals, was conducted in 2007 by Bart van der Worp et al. This publication provided further justification for human study by showing a mean improvement of one-third in tissue recovery as a result
of hypothermia in animal models suffering from ischemia\textsuperscript{10}. The study compared on the basis of infarct size, determining a mean reduction by 44%, with the largest in the \(\leq 31^\circ\text{C}\) group, however mild levels of hypothermia at \(35^\circ\text{C}\) still showed a 30% reduction of infarct size. This is significant showing even mild levels of hypothermia reduce the area of tissue death.

Current mechanical thrombectomy devices can remove a blockage but do not couple with therapeutic hypothermia. A unique blood cooling system may synergize with current mechanical thrombectomy devices into a single tissue salvage solution. This combination has delivered rapid brain tissue cooling - up to \(8^\circ\text{C}\) in under 5 minutes during canine testing\textsuperscript{11}.

**Problem Statement:**

Current research has not predicted discrete tissue temperatures during a localized therapeutic hypothermia procedure in the brain. Current models approach the problem from a physiological and clinical perspective while using a simplified quantitative engineering model that cannot precisely predict discrete tissue temperatures\textsuperscript{12,13}.

A theoretical brain model for cooling was proposed in a 2008 paper by Neimark et al. to determine the mean time required for deep brain tissue to reach optimal cooling levels via a saline solution\textsuperscript{12}. The study determined that within 10 minutes deep brain tissue would reach hypothermia levels of \(32^\circ\text{C}\). The study made numerous assumptions using a 3D hemispheric model divided into four tissue layers based on continuum model concepts. The Circle of Willis which consists of the major cerebral arteries was simplified to a linear model, ignoring pulsatile flow entirely. Another simplified model was employed by Wang et al. in 2008 to verify experimental data for targeted hypothermia in rats using an interstitial cooling device\textsuperscript{13}.

These papers were unable to predict discrete tissue temperatures at precise locations commonly associated with ischemic stroke. Predicting the amount of cooling needed and the amount of treatment time required is critical; these factors (delivered flow rate and fluid temperature) must be optimized to maximize patient benefit. Published methods do not predict the temperature distri-
bution at a specific site of common ischemia, such as the middle cerebral artery (MCA) which directly follows from the internal carotid artery (ICA), Figure 2.

Figure 2: A lateral angiogram highlighting the ICA and MCA. The target area for thrombectomy procedures and computational modeling is highlighted in red\textsuperscript{14}.

Goal:

To create a 3-Dimensional computational fluid dynamics heat transfer model of the target area highlighted in Figure 2. To accurately predict the temperature distribution of brain tissue surrounding the cerebral artery network during therapeutic hypothermia enhanced thrombectomy procedures. This will allow for an accurate prediction of the effect that delivered fluid temperature and flow rate have on surrounding brain tissue temperature distribution. This will inform optimal operating conditions for a system used to cool specific regions of the brain.
References


