



# Suction force-suction distance relation during aspiration thrombectomy for ischemic stroke: A computational fluid dynamics study



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## ABSTRACT

Acute Ischemic Stroke (AIS) is the major type of stroke occurring in patients. Aspiration thrombectomy, which uses suction to remove the thrombosis, is a promising technique in the clinical treatment of AIS patients. In this research a computational fluid dynamics (CFD) analysis was conducted to model the blood flow dynamics in a simplified cerebral model during an aspiration thrombectomy procedure. The flow system being analysed was a typical in vitro cerebral flow model, and the system parameters were set based on the clinical and in vitro data reported in open literature. The simulated flow field features showed good correlation with the in vitro response as reported in literature. The CFD study provides detailed technical data including the peak velocity occurring at the catheter tip and the suction force-suction distance relation during the aspiration thrombectomy procedure, which are useful new knowledge and have the potential to influence future catheter design as well as clinical operational protocols used during thrombectomy intervention.

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## 1. Introduction

Stroke is the third most common cause of death worldwide and the number of people suffering a stroke annually has increased in the last twenty years resulting in a significant increase in stroke-related deaths and disabilities ([1]). Ischemic stroke accounts for about 80% of all stroke cases and occurs when one or more arteries that supply blood to the brain are occluded by a thrombus. Good recovery and improved outcomes in ischemic stroke patients are highly dependent on the time taken to restore blood flow to the brain ([2]). The most widely used approach to restore blood flow rapidly is a technique called thrombolysis which uses enzymes to break up the clot. However, recanalization rates with intravenous thrombolysis are poor in patients with occlusion of large intracerebral arteries such as in the basilar artery or proximal middle cerebral artery ([3]).

An alternative, endovascular treatment, is associated with

considerably higher recanalization rates than intravenous thrombolysis ([2]). The most commonly used methods for endovascular treatment are mechanical thrombectomy (using a mechanical retrieval device to grab and remove the thrombus) and aspiration thrombectomy (using a pump or syringe with high negative pressure to suck and remove the thrombus). Aspiration thrombectomy achieves consistently higher recanalization rates than the mechanical thrombectomy, but clinical outcomes with aspiration thrombectomy are variable ([4]), with very poor recovery rates in four studies ([5–8]) and good outcomes in others ([9–12]). However, a recent prospective study has reported improved clinical outcomes using a large bore aspiration catheter ([13]) and there are compelling reasons to use aspiration thrombectomy for clot removal over mechanical thrombectomy including efficiency and cost effectiveness. This is reflected in the appearance of new aspiration devices that claim to have design features that improve aspiration efficiency. However, little is known of the interaction between aspiration devices and clots or of flow conditions within the brain and these factors have significant influence on the aspiration efficiency. Another factor is the variability between interventionists in the use of aspiration devices in the clinical setting. Therefore increasing our understanding of thrombus-device

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### Nomenclature

D	Diameter
$f$	frictional force
F	Force
L	Suction distance, i.e., the distance between the catheter tip and the proximal surface of the thrombus
P	Pressure
S	Suction force, i.e., summation of all the pressure forces acting on the proximal and the distal surfaces of the thrombus

### Subscripts

cc	surface contact action between the catheter tip and the thrombus surface
pc	pressure action on the surface of the thrombus (due to catheter suction)
pd	pressure action on the distal surface of the thrombus
pp	pressure action on the proximal surface of the thrombus
p <sub>v</sub>	pressure action on the surface of the thrombus (due to the vascular intra-luminal pressure)
w	wall action

interaction and flow conditions in the cerebral circulation will help to improve device designs and operational techniques ([14]).

The aspiration thrombectomy technique is still in its infancy and needs substantial improvement before it can be accepted as a routine treatment procedure. For example, it is still not clear what are the optimal levels of suction pressure and pick-up force that should be applied to remove thrombi of different sizes, different stiffness, and in different cerebral vessels; what is the exact relation between the suction force produced on the thrombus and the suction distance (i.e., the distance from the suction catheter tip to the thrombus). This information is important as it will directly influence the operational protocols of the aspiration thrombectomy procedure. Different views are held about the optimal choice of the suction distance in order to achieve the maximal suction force. Tunuci et al. ([15]) maintained their catheter tip 3–5 mm away from the proximal side of the clot during aspiration in order to achieve the maximal suction; Pearce et al. ([16]) used 3 mm suction distance instead, while most other researchers ([11,14,17,18]) preferred to fully engage the catheter tip onto the thrombus surface in order to produce the maximal suction. It is hard to judge which one is the best choice until an in-depth study is conducted into the suction force-suction distance (S-L) relation.

The detailed flow condition in the aspiration thrombectomy procedure is influenced by multiple factors, including the distorted flow profile due to the irregular geometry of the brain vessels, nonlinear contact and frictional forces between the thrombus and the vessel wall, and the suction action produced by the aspiration intervention. To study this complex response process, researchers have built mechanical fluid flow systems as simplified representations of the cerebral flow loop, and conducted in vitro tests to observe the flow features around the blood clots during different mechanical thrombectomy procedures ([14–16]). These in vitro studies helped to reveal the catheter-thrombus interaction features to some degree. However, with the simplified mechanical representation and the restriction of the small vessel geometry only discrete pressure/flow signals can be collected at selected locations,

and video images recorded to provide a rough description of the overall flow picture. The data and images recorded in this manner are insufficient for the evaluation of the suction force in the aspiration procedure, while suction force is an important parameter as it is a more direct and descriptive way of predicting the outcome of aspiration intervention.

Computer modelling is a mature research tool that has been widely applied in the study of engineering and biomedical applications. Specifically in the area of cerebral blood flow modelling, computational fluid dynamics (CFD) is one of the major techniques being used by researchers to simulate the complex blood flow responses in different healthy and diseased conditions ([19–23]). However, published CFD studies of aspiration techniques and cerebral flow are scarce, with only one recent study reporting a simple CFD analysis used in conjunction with an in vitro study on a mechanical model ([14]).

This study focused on the CFD modelling of the flow features in the middle cerebral artery during the aspiration thrombectomy procedure. For comparison with previous in vitro data, this study used the flow domain similar to that in the mechanical system built by Lally et al. ([14]). The initial CFD data for the two cases (with and without thrombus) in the vessel were compared with the results of Lally et al. for qualitative validation. Following this, CFD analysis was extended to reveal the S-L relation in the aspiration thrombectomy.

## 2. Methods

This study analysed the fluid flow response during aspiration intervention in an in vitro test rig. The general configuration of the test rig was the same as that used in the study of Lally et al. ([14]). Also the system operating conditions such as the pressure head applied to the flow loop were kept consistent. However, to facilitate model construction and to reflect more general situations, some geometrical details, e.g. minor variation of cylindricity and minor bending at the two ends of the glass tube as the vessel model, small round corners at the tip of the catheter etc., which were difficult to quantify, were neglected in the current study.

### 2.1. CFD analysis

In conducting the CFD analysis, the fluid was considered to be incompressible and Newtonian, with a density of 1300 kg/m<sup>3</sup> and a dynamic viscosity of 3.2 cP, to match the properties of the real blood ([24]). The elasticity of the vessel wall and that of the catheter wall were neglected. Thus the system dynamics are governed by the Navier-Stokes equation and the mass conservation equation. The aspiration intervention causes strongly disturbed vortex flow near the catheter tip, and the shear stress transportation model [25] was used to calculate the turbulence flow effect. Detailed flow domain geometry and the boundary condition settings were explained in the following sections that describe the simulation cases.

Ansys CFX version 17.0 running on a HP Z210 workstation (which has 4 CPUs and 8 Gb memory) was used to conduct the CFD analysis. The CFD calculation was considered as a steady simulation, with the convergence criterion chosen as the root mean squares of the residuals for the flow variables (including the pressure  $P$  and the three dimensional velocity components  $u$ ,  $v$ , and  $w$ ) being below 10 to the minus 5th power. The education license used had restrictions on the maximum scale of solvable problems, thus the maximum allowable mesh size has been used and no mesh independent test was conducted. This would influence the accuracy of the detailed values in the final solution but would not change the nature of the results which would be meaningful for this initial stage of study.

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