# IMPACT OF CEREBROSPINAL FLUID FILTRATION ON SUBARACHNOID HEMORRHAGE CLEARANCE: A COMPUTATIONAL FLUID DYNAMICS STUDY

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## INTRODUCTION:

Subarachnoid hemorrhage (SAH) is a severe and often-fatal event in which blood is released into the cerebrospinal fluid (CSF) due to intracranial insult, ruptured intracranial aneurysm, and/or other head trauma. Early and rapid filtration of blood and blood breakdown byproducts post-SAH may reduce the incidence of stroke, cerebral vasospasm. The present study objective was to formulate a computational model to see the impact of the Neurapheresis™ system on CSF flow velocities, steady-streaming, and subarachnoid blood clearance by comparing it to a case with lumbar drain only.

Neurapheresis therapy involves aspiration of CSF from the lumbar spinal subarachnoid space (SAS), filtration of blood and/or other pathogens specific to the malady, and then return of filtered CSF to the SAS at the thoracic spine, via redundant fenestrations (to avoid clogging or blockages) in the dual-lumen catheter (**Figure 1**).

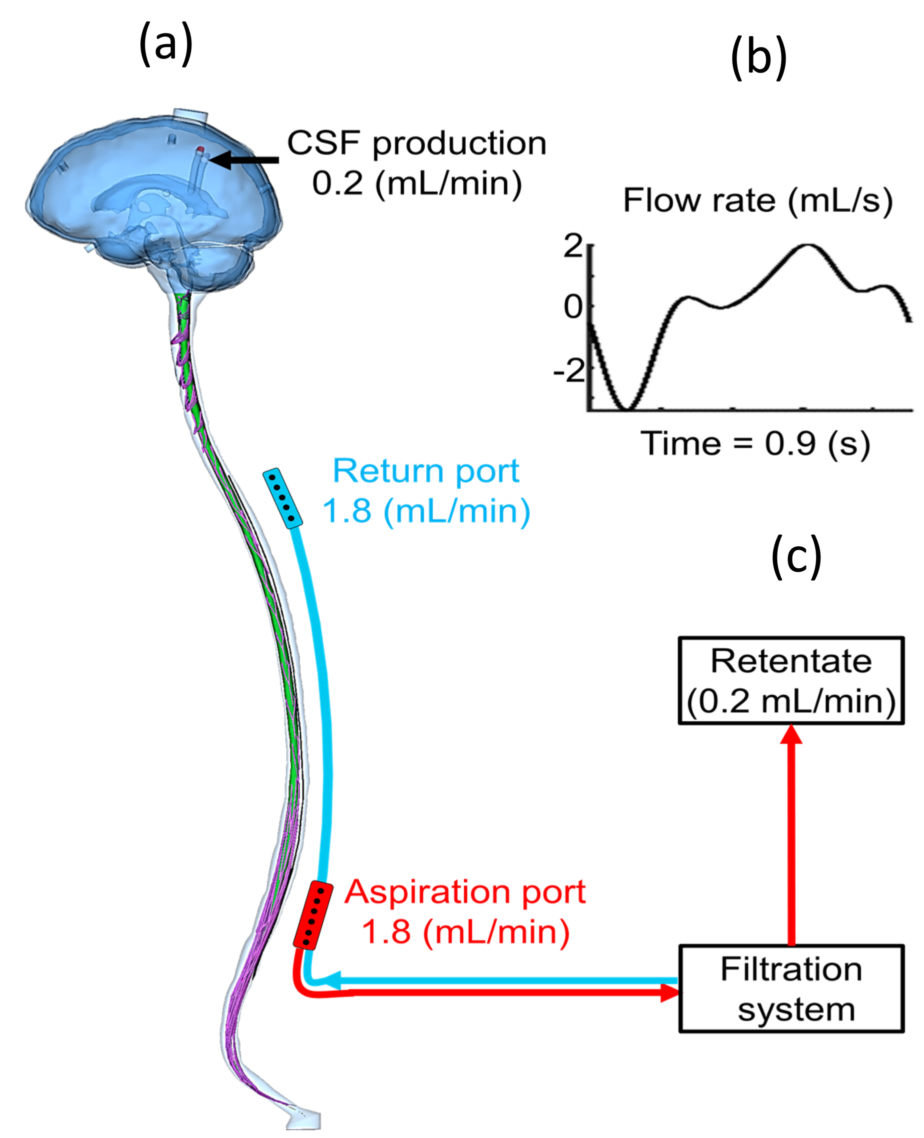


**Figure 1: COMPUTATIONAL MODEL**

(a) 3D computational model of the SAS with filtration system. (b) Oscillatory CSF flow rate. (c) Neurapheresis therapy Filtration system

## METHOD:

A multiphase computational fluid dynamic (CFD) model of the SAS was built using ANSYS Fluent 19.1. Spinal geometry was defined by our previously developed model [1]. A detailed intracranial CSF space geometry was added to the spinal SAS based on high-resolution MRI **(figure 3**). A dual-lumen catheter geometry was added to the posterior SSS at the T2-L2 level and positioned at the midline (**Figure 1a**). The final computational mesh comprised 14.8 M cells. Flow boundary conditions reproduced subject-specific non-uniform CSF flow along the spine (**Figure 1b**) by imposing non-uniform dura deformation [2]. CSF was considered to be incompressible with a density of 993.8 kg/m3 and Newtonian with a viscosity of 0.693 mpa·s. To visualize steady-streaming along the spinal axis due to convective acceleration of oscillatory flow within an eccentric annulus, the cyclic mean sagittal velocity, $U_{z\text{-}mean}$, at each node was calculated. This steady-streaming velocity field was then held constant (''frozen flow field'') to compute hemorrhage clearance [3].

Blood was modeled using a fluorescein tracer in the bulk fluid phase. An initial uniform tracer concentration of 10% was assumed. Neurapheresis system aspiration flow was set at 2.0 ml/min and return to 1.8 ml/min, for retentate of 0.2 ml/min (**Figure 1c**). Lumbar drain CSF removal is 0.2 ml/min from the aspiration port.

## RESULTS:

Maximum Re was 180 and located within the cervical spine (**Figure 2a**). The sagittal $U_{z\text{-}mean}$ velocity profiles showed a region of caudally directed (↓) steady-streaming in the posterior SSS in the middle thoracic spine and in the anterior SSS in the cervical spine (**Figure 2b**). Average steady-streaming velocity for Neurapheresis therapy and lumbar drain was 0.19 and 0.09 (mm/s), respectively. Visualization of unsteady CSF velocity contours in the sagittal plane showed that peak CSF velocities occurred in the cervical spine (**Figure 2c**). CSF velocity profiles near the aspiration and return ports showed that most of the flow into and out of the domain originated from the first two holes at the return and the aspiration port (**Figure 2c1-2**).

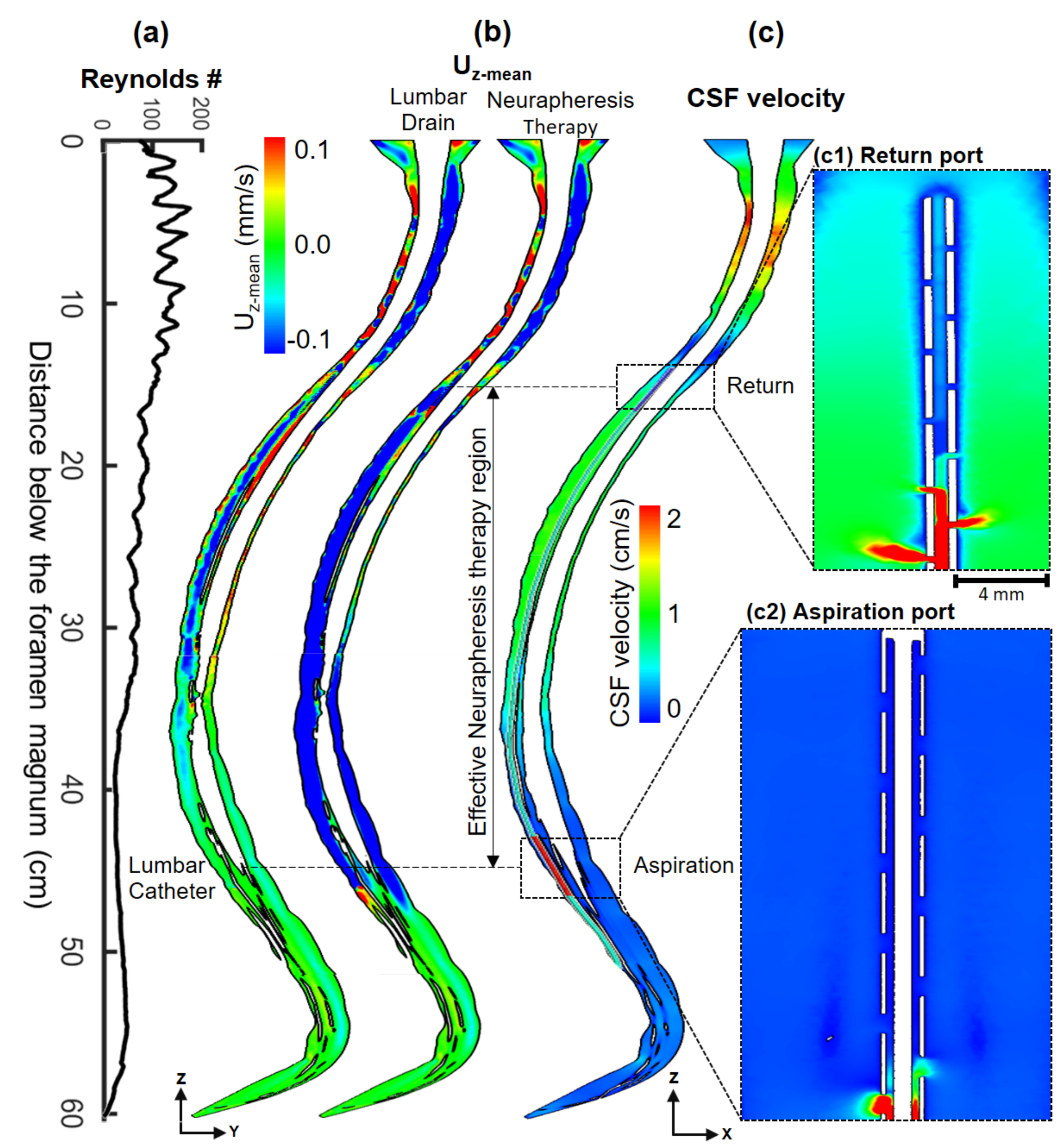


Figure 2: (a) Reynolds number distribution (b) Sagittal visualization of cyclic mean velocity, (c) Sagittal visualization of CSF velocity magnitude.

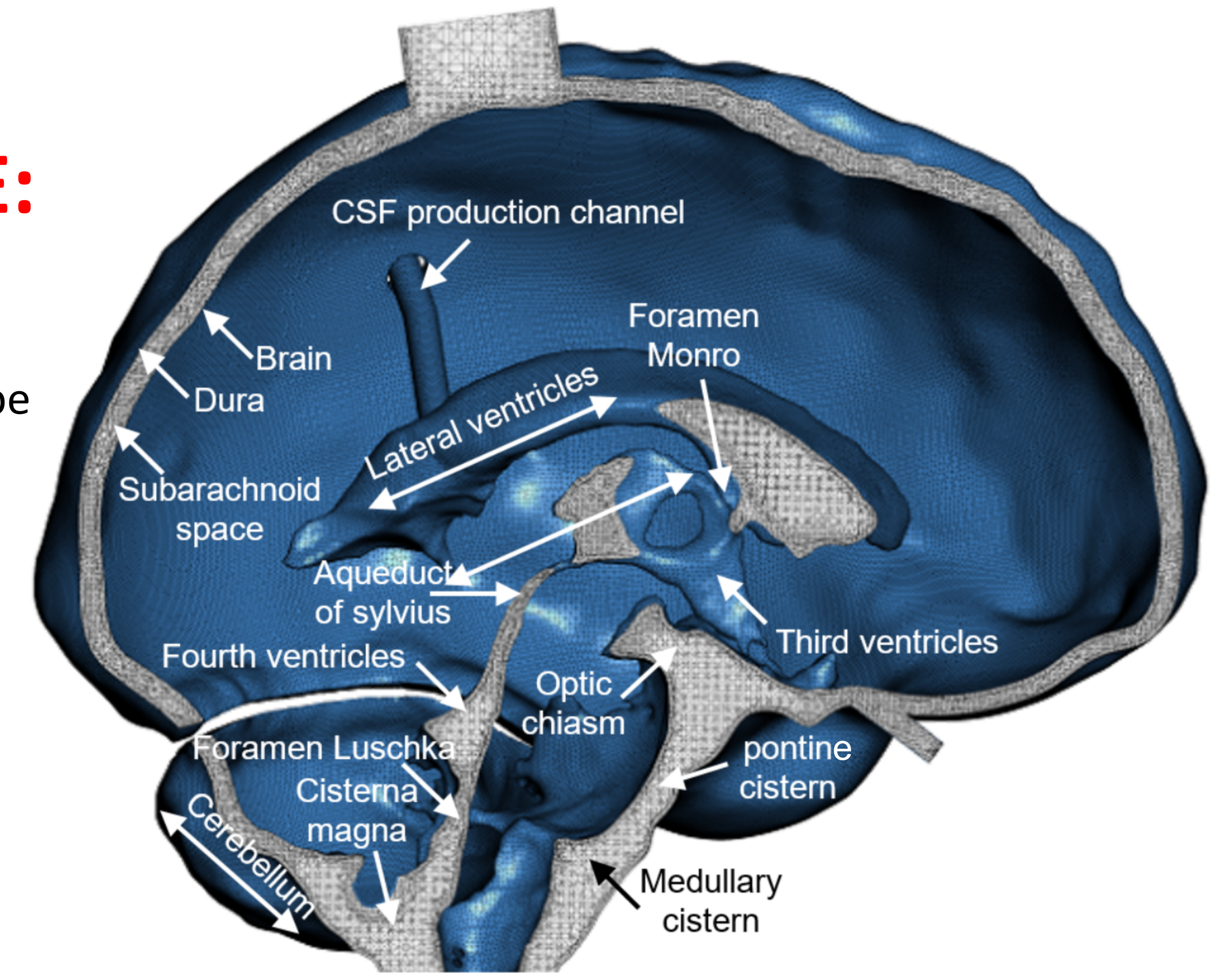


**Figure 3: Intracranial CSF space geometry**

3D Tracer concentration contours demonstrated that the lumbar and thoracic SSS were largely cleared of blood after 24 hours of Neurapheresis therapy (**Figure 4a**). The spatial-temporal concentration plots showed relatively rapid removal of blood from the thoracic SSS after 1 hr of filtration. 24 hours after Neurapheresis therapy, less than 10% of the initial blood concentration remained in the lumbar and thoracic spine and more than 70% was cleared from the cervical spine. In comparison, lumbar drain had a much lower impact on blood concentration reduction. After 24-hours of lumbar drain, blood concentration in the thoracic spine decreased to ~7% compared to <1% under neurapheresis therapy (**Figure 4b**).

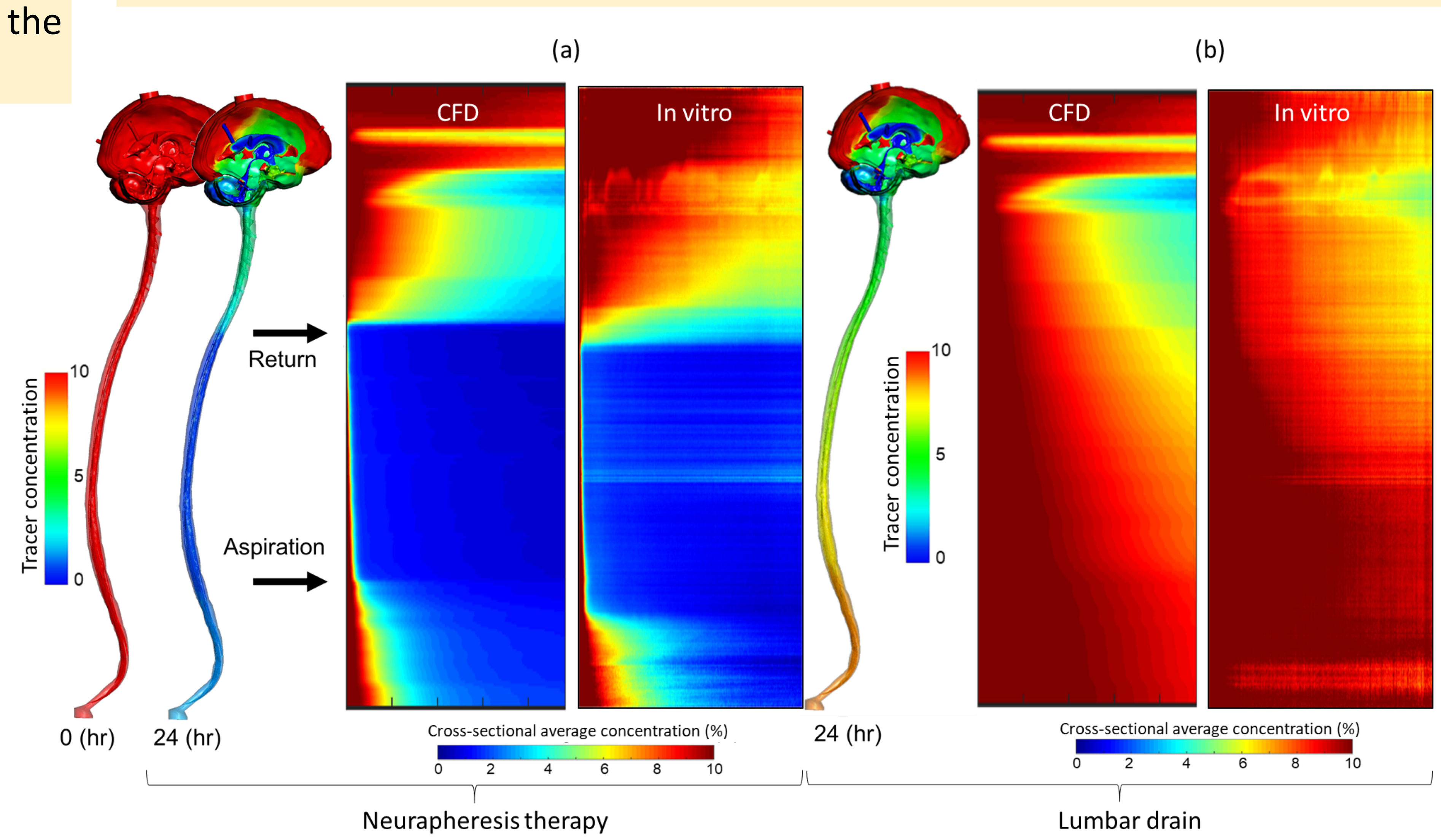


**Figure 4: Tracer concentration in 24-hour period**

(a) 2D tracer concentration contour. (b) Spatial-temporal tracer concertation plot

## CONCLUSION:

A subject-specific CFD model of the entire CSF system was formulated and applied to study the impact of Neurapheresis therapy on tracer removal from CSF. Neurapheresis therapy was found to significantly increase tracer clearance. The CFD model presented offers a platform to understand intrathecal device behavior as well as envision alternative Neurapheresis system protocols and devices. **CFD results were verified with in vitro model (see paper #420, Lucas Sass)**

## REFERENCES:

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