Real-Time Virtual Brain Aneurysm Clipping Surgery

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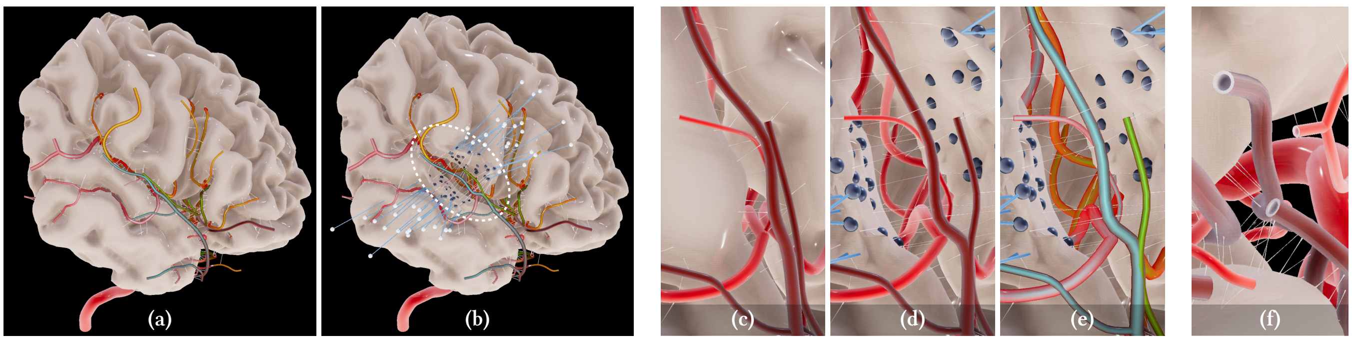

Figure 1: (a) Overview. (b) Deformation simulation by Position Based Dynamics. (c)-(e) Expansion views of (b). Hidden blood vessels inside the brain have been exposed by the brain's deformation. (f) Blood vessels reconstructed from central lines info.

ABSTRACT

We propose a fast, interactive real-time 3DCG deformable simulation prototype for preoperative virtual practice of brain aneurysm clipping surgery, controlled by Position Based Dynamics (PBD). Blood vessels are reconstructed from their central lines, connected to the brain by automatically generated thin threads "virtual trabeculae", and colored by automatically estimated their dominant region.

CCS CONCEPTS

• **Computing methodologies** → *Visibility*; *Virtual reality*;

KEYWORDS

Simulation, Medical, Brain Aneurysm, Clipping Surgery, Position Based Dynamics

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1 INTRODUCTION

A cerebral aneurysm, or a brain aneurysm is a bulge like a ballon on a brain artery, and is found in about 3.2% of the adult population worldwide [7]. One of the treatments is surgical clipping, by which a small clip is placed across the neck of the aneurysm through an opening in the skull and a sulcus of the brain [3]. One of the approaches to a brain aneurysm is transsylvian approach that pulls and opens Sylvian fissure, a deep sulcus between the frontal lobe and the temporal lobe of the brain (Figure 2(b)). During the surgery, neurosurgeons have to decide and move each blood vessel branch located in Sylvian fissure to either the frontal or the temporal lobe side, according to the blood-vessel-branch dominant region.

There are several attempts to simulate the surgery [1, 2], but they mainly focus on the clipping instead of reaching the aneurysm from the brain surface, and the deformation simulation is very limited. So we have developed a fast, interactive real-time 3DCG deformable simulation prototype of opening the sulcus of the 3DCG brain. We have chosen to use approximate but fast simulation method, PBD [4] rather than more accurate one such as finite element method because what neurosurgeons want to know is not the accurate

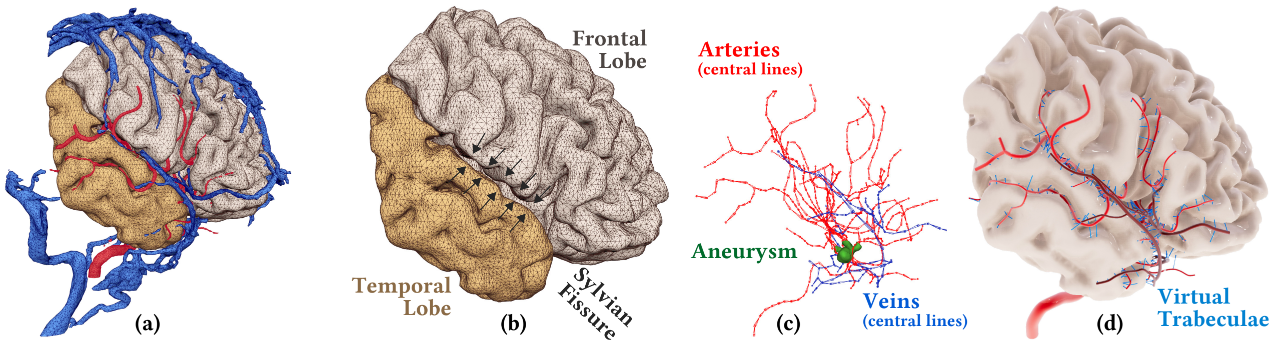

Figure 2: (a) Original extracted polygon meshes from Magnetic Resonance Imaging (MRI) and 3D Rotational Angiography (3DRA). (b) Input data (brain). (c) Input data (blood vessels and aneurysm). (d) Automatically generated virtual trabeculae.

deformation, but relative positional relationships of each blood vessel branch when the brain sulcus is pulled and opened, and it's dominant region. Our work builds on Shono et al.'s work on clipping simulator [6], but it requires a lot of manual time-consuming steps for processing 3D data, while our prototype needs only brain surface mesh(es) and the central lines of the blood vessels.

2 METHOD

2.1 Input Data

Two triangulated partial brain polygon meshes (the frontal lobe and the temporal lobe) were manually extracted from a patient's MRI by neurosurgeons using Thermo Scientific™ Avizo™. Noisy blood vessel ones were manually extracted as well from the 3DRA (Figure 2(a)). The central lines of the blood vessels were also manually extracted by the first author using Autodesk® Maya®, which are necessary for our simulation system (Figure 2(c)).

2.2 Blood Vessel Mesh Reconstruction

Blood vessel meshes were reconstructed from their central lines which include the radii at each vertex. We applied a method [5] to make thick, hollow and better-looking blood vessels (Figure 1(f)).

2.3 Automatic Synthesis of Virtual Trabeculae

We automatically made "virtual trabeculae" which connects blood vessels and the brain (Figure 2(d)). The closest vertex on each brain surface from each vertex of the central lines of the blood vessels is searched, and the length between the two vertices is stored first. The line segments, or "virtual trabeculae" which intersect the brain or the blood vessels are eliminated. We assumed the length roughly follows a normal distributions so ones whose length are outside of mean ± 2SD (standard deviation) are also eliminated. Anatomically, the actual arachnoid trabeculae from blood vessels connects to the arachnoid mater, instead of the brain surface, but this "virtual trabeculae" is easy to calculate and makes it possible to move blood vessels in accordance with the deformation of the brain.

2.4 Blood-Vessel-Branch Dominant Region

We automatically estimated each blood-vessel-branch dominant region (either the frontal or the temporal lobe) by first looking at the most peripheral end tips of the branches, and looking back toward central ones. If all the child branches of a branch belong to the same region, we considered the branch also belongs to the same region. This estimation is not always true but helps a lot by being visualized with different colors (Figure 1(a), (b) and (e)).

3 RESULT

We have implemented the simulation prototype on Microsoft® Windows® 10 PC with CPU Intel® Core™ i7-7700K 4.2GHz, Memory 64G, GPU NVIDIA® GeForce® GTX 1080Ti, and on Epic Games Unreal Engine 4.16. The users interact with it by a usual 2D display, a keyboard and a mouse. We have tested three brain data set, and the frame per second (FPS) was about 40 - 60 FPS (Figure 1).

4 FUTURE WORK

The virtual arachnoid mater which covers the brain and the blood vessels, more interactive user interface like cutting the arachnoid mater and trabeculae, and pulling blood vessels in addition to the brain are also essential for better simulation and clinical usage.

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