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NOVEL PATIENT-SPECIFIC COMPUTER MODELLING OF STENT RETRIEVER THROMBECTOMY

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INTRODUCTION

Stent retriever thrombectomy (SRT) for Acute Ischemic Stroke (AIS) aims to physically remove the occlusive clot. The main goal of SRT is the restoration of blood flow in one treatment pass. However, only ~30% of treatments are successful in the first pass [1], while the rest need to undergo more attempts that are associated with added mortality and mobility. Computer simulation of SRT can help understand underlying factors in unsuccessful cases and create a testbed for developing safer, more effective devices.

To date, few SRT computer models have been developed, but none can realistically simulate the complex stent-clot interactions, especially in failed cases. Finite element analysis (FEA) and XFEA based models were tested for patient specific models [2,3], but these models were not able to show the clot fragmentations or embolus dissection from the clot1's mass. Moreover, most previous computer models were developed for ideal geometries which do not consider the effect of the patient's vessel geometry [4].

Recently, we developed a method to accurately model the clot behavior in interaction with stent wires, which was even able to simulate clot fragmentation and embolus creation in failed cases [5]. In order to consider the vessel geometry in our simulation, we are expanding our method for patient specific vasculature and proposing a new workflow to model the SRT. Our new workflow is capable of accurately addressing two major problems faced in previous studies. Firstly, our clot model, which uses a hybrid FEA-SPH technique, realistically simulates the tissue's behavior in failed cases where an embolus could be created or the clot does not get retrieved at all. Secondly, it is implemented in patient specific vasculature geometries to accurately capture the effect of parent vessel geometry and Circle of Willis configuration.

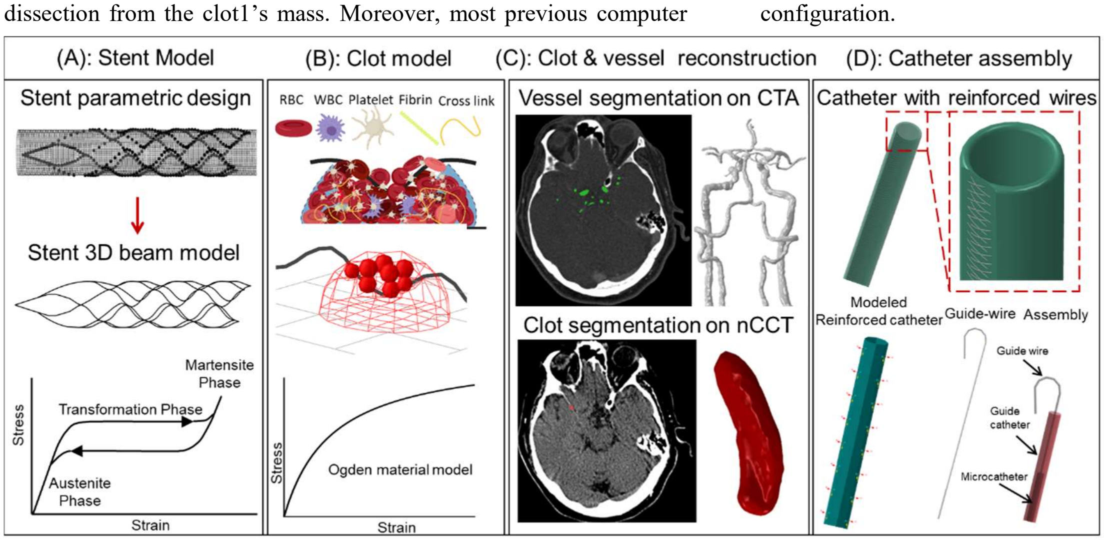

Figure 1: Modeling Workflow. A). The stent parametric geometry and nitinol superelastic behavior. **B).** The clot's hybrid FEA-SPH model and hyperelastic material behavior. **C).** Reconstruction of the patient's cerebral vessels and clot geometry from nCCT and CTA. **D).** The catheterization device assembly including microcatheter, guide-wire and guide catheter are also modeled to capture pre-deployment and retrieval steps.

METHODS

In our method, all the parts involved in a thrombectomy procedure were modeled assuming that the blood flow is arrested. The major modeled components include the stent, clot, vessel, and wire-guided catheter. To model different parts, considerations for each portion of the device are applied individually to assure the accuracy of the simulation. Our workflow is illustrated in Figure 1.

Stent model: The stent model follows a parametric design procedure as detailed in [5] in which different parameters are modifiable like cell size and shape, stent length and diameter, overlapping edges distances, working length versus nonworking length ratios. After having stent's geometry, Timoshenko beam elements and superelastic material behavior of nitinol was assigned to the stent's wires.

Clot model: The hybrid FEA-SPH model for clot was developed and explained in details in our previous work [5]. In this method, a combination of grid-based FEA and meshless SPH methods was implemented. In the beginning, clot is in FEA mode and as it deforms under the loading, elements which their strain passes a threshold convert to more flexible and separable particles.

Vessel and clot reconstruction: The realistic geometry of vessel was reconstructed from CTA images of real patients (UB institutional review board study 00002092). Also, the geometry of the same patient's clot was reconstructed from nCCT.

Catheter assembly modeling: Catheterization to deliver the stents to a clot's site include using a guideare, guidecather and microcather in combination. Real Microcather and guidecathers are reinforced with embedded wires, to model them we used shell elements for both catheters with rebar reinforcement. Guide wire was modeled as J-shape with beam elements and modified material properties to consider its multi-structure and maneuverability.

RESULTS

Figure 2 shows the results for a failed case in which the clot was not retrieved. As seen, in this workflow, all five steps of a real thrombectomy procedure were successfully simulated: (1) placing the stent into a packager, (2) deploying the microcatheter to pass the clot, (3) delivering the stent to the clot site, (4) deploying the stent across the clot so it can engage the tissue (done by holding the push wire and unsheathing the catheter), (5) attempted retrieval of the clot by pulling the stent through the cerebral vessels. As it can be seen, the stent was not able to hold the clot after cavernous curve, and failed to retrieved it.

DISCUSSION

We developed a workflow that was able to accurately capture the real behavior of clot and stent in a thrombectomy procedure. Since catheter deployment and its positioning against clot is a driving factor in the deployment of a stent into the clot mass, we also modeled the catheter deployment procedure. In the example case, we showed that our model simulates different behaviors of different parts in a thrombectomy procedure accurately including passing a catheter from clot, penetration of stent wires into a clot and engaging with it, fragmentation of clot under the stent's load, and the separation of the clot from stent. The clot's FEA-SPH solver accurately simulated the dynamic clot behavior throughout, as it was deflected and moved by the wire and catheter, began breaking, and then dissociated from the stent.

This workflow represents a significant advance compared to previous models that have been unable to model failed SRT cases (e.g. clot fragmentation during retrieval). In the future, we will implement our method on larger cohorts of patient-specific cases to study how different factors, such as like vessel tortuosity, clot material and mechanical behavior, , catheter deployment and stent retrieval techniques, contribute to successful or unsuccessful SRTs.

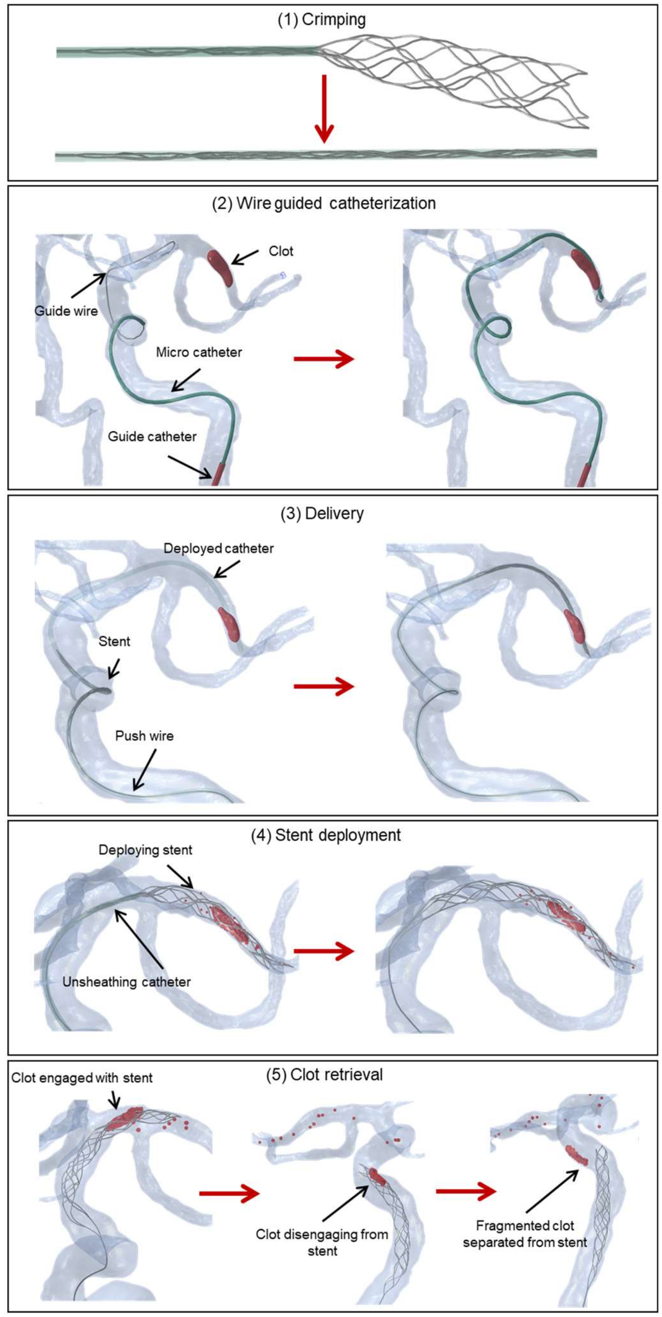

Figure 2: A Patient-Specific SRT Case. All components of SRT are modeled, including stent packaging, wire manipulation and microcatheter deployment, clot interaction with the stent, and retrieval. As seen here, SRT was unsuccessful in retrieving the clot past the cavernous ICA region.

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