A CLOT COMPOSITION DEPENDANT HYPERELASTIC MODEL IN THE SIMULATION OF DIRECT ASPIRATION THROMBECTOMY

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Introduction

Despite recent advancements in the treatment of acute ischemic stroke (AIS) by the use of stent retriever mechanical thrombectomy, complete recanalization of the occluded cerebral vessel is achieved in only 85% of cases, and 80% of AIS patients still suffer long-term disabilities [1]. Clot fragmentation and multiple clot removal attempts are associated with poorer clinical outcomes [2]. Fragmentation risk is associated with red blood cell (RBC) -rich clots rather than fibrin-rich clots [2,3]. Direct aspiration (DA) is an emerging alternative treatment for AIS. In DA procedures, a catheter contacts the distal face of the clot, and a negative suction pressure is applied in order to remove the clot from the vessel [1,2]. Currently, large-bore catheters are being developed with the goal to increase DA efficacy [2]. The influence of catheter design and blood clot composition on DA clinical outcomes has not been systematically investigated to date [4].

The current study outlines the first analysis of the effect of DA catheter diameter on clot deformation and fracture by the use of a finite element framework to simulate the aspiration of RBC- and fibrin-rich clots.

Methods

Considered is a cylindrical clot (3 mm in diameter) in direct contact with the distal end of a catheter with diameters of 1.2 mm, 1.62 mm, and 2.5 mm (Figure 1A). A negative suction pressure results in deformation of the clot into the catheter, characterised by the aspiration length *u*. In a fully successful DA procedure, the entire clot is ingested into the catheter when a critical pressure is reached. The clot material is modelled using a customized composition-dependent anisotropic hyperelastic constitutive law implemented as a user defined material subroutine (UMAT) in Abaqus [3,5]. This formulation incorporates non-linear volumetric and isochoric deformation of the RBC components of the clot, in addition to an anisotropic deformation of the fibrin network. Model parameters for RBC- and fibrin-rich clots were calibrated using experimental multi-axial test data [3].

Results

As shown in Figure 1B, RBC-rich clots aspirate further into the catheter than fibrin-rich clots at any sub-critical pressure. RBC-rich clots are also fully ingested at a lower critical pressure. Figure 3C shows that an increase in catheter diameter results in a lower critical pressure for full ingestion. The maximum principal stress in RBC-rich clots exceeds the measured fracture strength (0.01 MPa [2]), whereas stress levels computed in fibrin-rich clots do not exceed the measured fracture strength (0.045 MPa [2]) (Figure 1D). Finally, Figure 1E shows that clot compressibility is a key determinant of the success of DA.

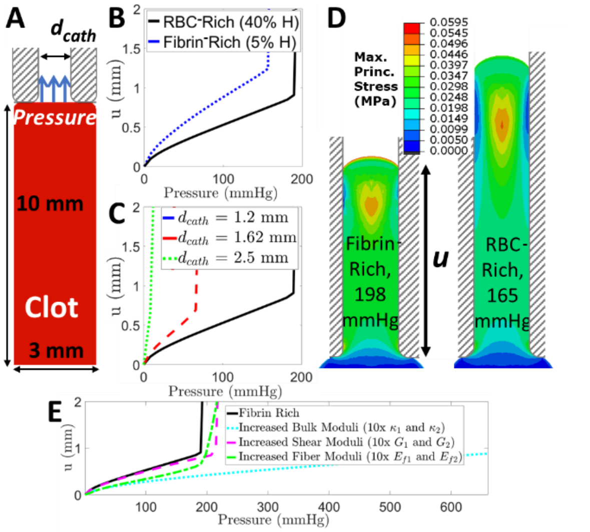

Figure 1: A) FE model of the clot and catheter. B) Aspiration length (u) versus applied pressure (d_{cath} =1.2 mm). Dramatic increase in slope shows initiation of full ingestion. C) Influence of catheter diameter on DA of a fibrin-rich clot. D) Distribution of maximum principal stresses (d_{cath} =1.2 mm). E) Parametric investigation on the effect of material moduli.

Discussion

Our study presents the first FE analysis of DA thrombectomy. The obtained results support the clinical observation that fibrin-rich clots are more resistant to full ingestion into a DA catheter [6]. However, our results suggest that RBC-rich clots have a higher fragmentation risk, similar to clinical findings for stent retrievers [3]. Our findings also indicate that the use of large-bore catheters increases the probability of full ingestion and reduces the fracture risk.

References

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