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A Thermodynamically Consistent Multiphysics Framework for Fibrin Network Assembly During Blood Coagulation

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Abstract

The formation of force-bearing biological networks is fundamental to a wide range of physiological and pathological processes, including embryogenesis, metastasis, and hemostasis. However, traditional continuum theories, such as Larché-Cahn or Mixture Theories, are often insufficient for capturing the transient assembly and disassembly of force-bearing domains. Consequently, new formulations are required to accurately describe these dynamic mechanobiological processes. The primary objective of the current work is the development of a robust multiphysical and computational model dedicated to the fundamental transition of fibrinogen into fibrin during blood coagulation. Although the biochemical pathways of the coagulation cascade are extensively documented, the mechanobiological influence of platelets on clot remodeling and subsequent tissue repair remains a burgeoning frontier of research. While existing comprehensive models [1] have addressed large-scale platelet deposition under flow conditions, there remains a critical need for high-fidelity frameworks capable of resolving the intrinsic kinetics of structural network assembly. To bridge the gap between experimental observation and theoretical prediction, this research integrates state-of-the-art microscopy [2, 3] with an innovative theoretical framework [4, 5]. We present a novel mechanobiological model focusing on the dynamic polymerization of fibrinogen

into fibrin, which couples mechanical, chemical, and transport phenomena within a unified, thermodynamically consistent multiphysics system. The governing equations derived from this framework are implemented via the deal.II library [6], employing High-Performance Computing techniques, such as adaptive mesh refinement on distributed triangulations, to solve the Lagrangian formulation through staggered algorithms. Outcomes demonstrate the model's capacity to replicate the growth dynamics of fibrin networks originating from activated platelets, offering a powerful predictive tool for investigating how mechanics affects blood clots.

Keywords:

Thermomechanics Finite strains Mechanobiology Blood Coagulation

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