**Fluid-Structure Interaction of collapsing bubbles in the proximity of soft biological tissue**

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**Abstract.** Biological flows involve large to extreme plastic deformations of the medium, which classical modeling approaches such as Immersed Boundary or Arbitrary-Lagrangian Eulerian methods fail to capture. To address this, we propose an explicit density-based diffuse interface model with Eulerian hyperelasticity. The model is implemented within a multi-dimensional adaptive mesh refinement framework with local time-stepping to investigate the fluid-structure interaction of shock-induced collapse of a single gas bubble near biological tissue. We examine the development of shear stresses during the collapse process. Our preliminary results show a complex dynamic between the bubble collapsing and the tissue that warrants further research.

1. Introduction

Bubble collapse near biological tissues has significance in biomedical applications like ultrasonic drug delivery, gene therapy, and histotripsy [1]. Understanding bubble collapse dynamics enhances the therapeutic potential of these techniques. Acoustic cavitation, where ultrasonic waves cause microbubble formation, growth, and collapse in a liquid medium, is central to this research [1]. Bubble collapse generates shock waves, microjets, and high local pressures, affecting surrounding tissues [2]. Sonoporation leverages these effects, creating transient pores in cell membranes for drug delivery [3]. In gene therapy, mechanical stress from bubble collapse improves the cellular uptake of genetic material [4]. Histotripsy, a noninvasive tissue ablation technique, relies on controlled cavitation to fractionate target tissues without harming adjacent healthy tissue [5]. Developing predictive models and experimental studies that address bubble dynamics, acoustic fields, and tissue properties is crucial for advancing these therapies [6]. Classically, deformable solids are modeled using Immersed Boundary (IB) or Arbitrary-Lagrangian-Eulerian (ALE) methods, both of which face challenges in handling large deformations due to mesh distortion and entanglement, resulting in computational instabilities and inaccuracies [7]. As deformations increase, mesh quality deteriorates, necessitating re-meshing and consequently increasing computational demands and introducing interpolation errors [8]. Alternatively, Eulerian methods are more suitable for simulating large deformations in solids as they decouple material and spatial coordinates, avoiding mesh-related issues [9]. In this context, an explicit density-based diffuse interface model is extended to include Eulerian hyperelasticity and has been validated against bubble dynamics and solid mechanics cases. We present the case where an ultrasound shock wave impacts a gas bubble in water standing at a distance from a soft material modelled as liver.

1. Numerical Method

The numerical simulation of fluid-structure interactions in the context of bubble collapse near elastic materials presents a multitude of challenges. These complexities arise from the need to accurately track multiple fluid & solid phases, accommodate compressible flow characteristics, account for significant material deformations, and capture shock wave propagation. The density based diffuse interface model developed by Kapila [10] has been expanded to incorporate Eulerian hyperelasticity:

where is the Cauchy stress tensor, is the specific total energy, is the symmetric left unimodular stretch tensor. The governing equations are supplemented by the saturation constraint . The closure of the model is achieved by specifying the expression for the internal energy where the stiffened gas equation of state and the neo-Hookean model were chosen: . The stress tensor is given by: , where p is the hydrostatic pressure, is the unimodular part of the left Cauchy Green strain tensor and G is the mixture shear modulus.

1. Results

In relation to biomedical applications, the study presented here involves the impact of an ultrasound shock wave on a gas bubble in water standing at a distance from a soft material modelled as liver. Since the acoustic impedance of water and liver are similar, the shock wave can penetrate the tissue without being reflected. The bubble slowly starts to collapse as we see a pressure gradient forming in (a). In the process of the bubble collapsing the liver is pulled outwards as seen in (a)(b) creating shear stress in the

(a)(c)(e)

(b)![Une image contenant graphique

Description générée automatiquement]()(d)Une image contenant graphique

Description générée automatiquement(f)

Figure 1 The shock induced collapse of a gas bubble near a soft material.

tissue near the bubble. Following the initial collapse, the liquid jet penetrates the tissue and persists in its inward movement until it is situated within the tissue (c)(d). As the secondary collapse occurs within the tissue, it generates vorticity, causing the liver to be pinched and entrained along the bubble path (e)(f). During this process, stress remains localized in the vicinity of the interface and increases as the bubble penetrates the tissue.

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1. Conclusion

The presented research extends an explicit density-based diffuse interface model to incorporate Eulerian hyperelasticity. By examining the impact of an ultrasound shock wave on a gas bubble in water near a soft material modeled as liver, this work contributes valuable insights into the complex interplay between bubble collapse, acoustic fields, and tissue properties, paving the way for improvements in related therapeutic applications.

1. References

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