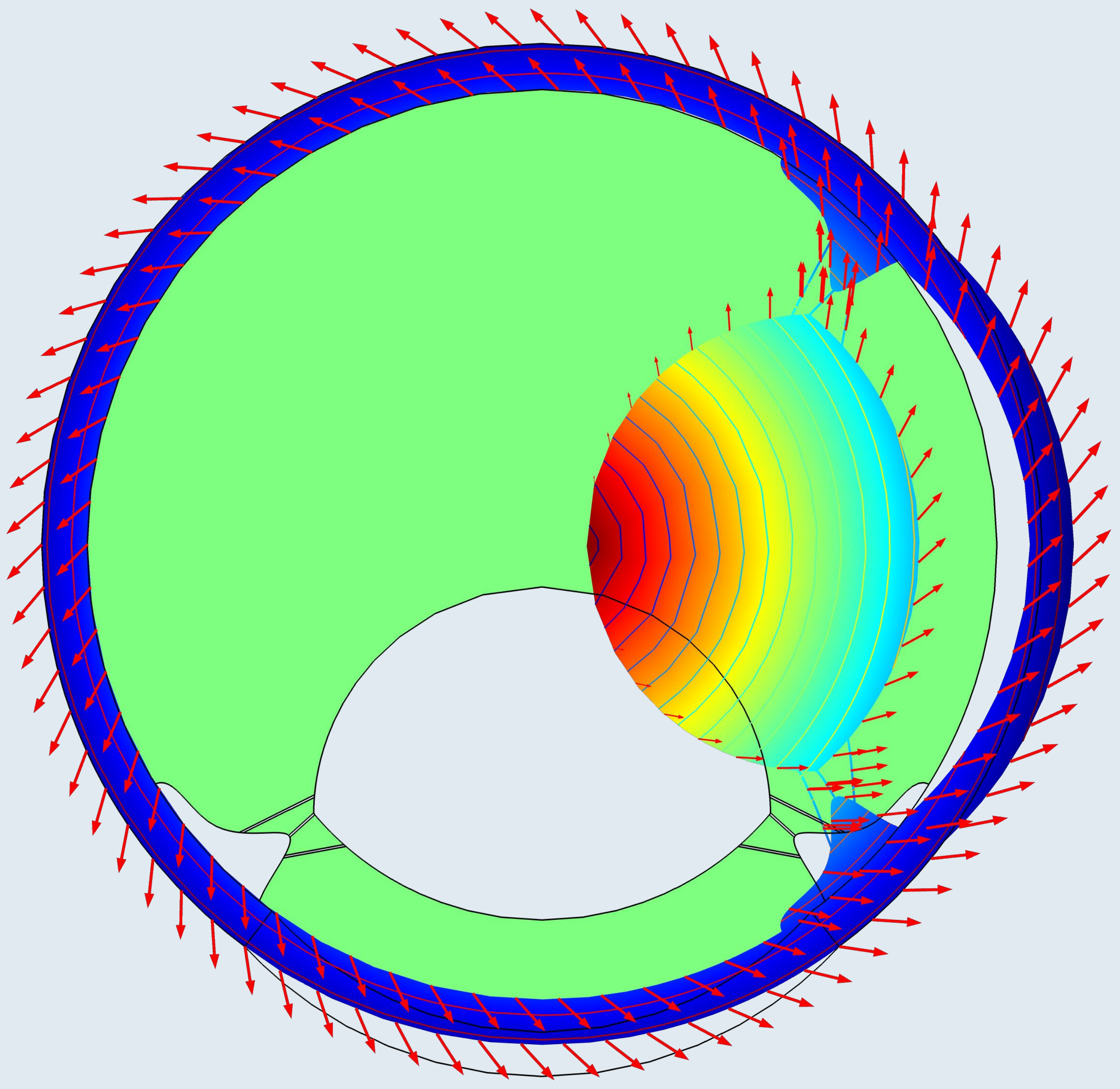

Investigation of the Crystalline Lens Inertial Overshooting: Ex Vivo and Simulation Results

Exploring the mechanical responses of the crystalline lens when facing with the overshooting phenomenon resulting from inertial forces following the sudden cessation of rotational motion of the porcine eyeball.

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Abstract

Utilizing Fluid-Structure Interaction (FSI), a 2-dimensional model of a porcine eye was implemented in FE modeling software. Both the geometrical and mechanical parameters of the model were based on earlier literature reports. The numerical in silico experiment was designed to be reconstruct the our own ex vivo tests, where the eye underwent a 90° rotation around the axis orthogonal to the plane of the model, with concurrent recording of the actual lens positions. Subsequently, a Purkinje performance optical simulations were conducted using the FEM simulation's output. Finally, the outcomes of such a computation workflow were compared with the data obtained from ex vivo experiments conducted on fresh porcine eye. The simulation outcomes reasonably aligned with the experimental results. Following the sudden cessation of the rotational motion, some small lens overshooting was manifested, followed by stabilization, primarily attributed to the damping effect, likely associated to the zonular fibers and ciliary muscle.

Material properties of the porcine eye.			
Modelled parts	Young's modulus [MPa]	Poisson's ratio [-]	Density [kg/m^3]
Sclera	28	0.49	1400
Cornea	12	0.48	1400
Ciliary Muscle	11	0.45	1600
Lens	1.5	0.49	1100
Zonular Fiber	0.35	0.45	1000

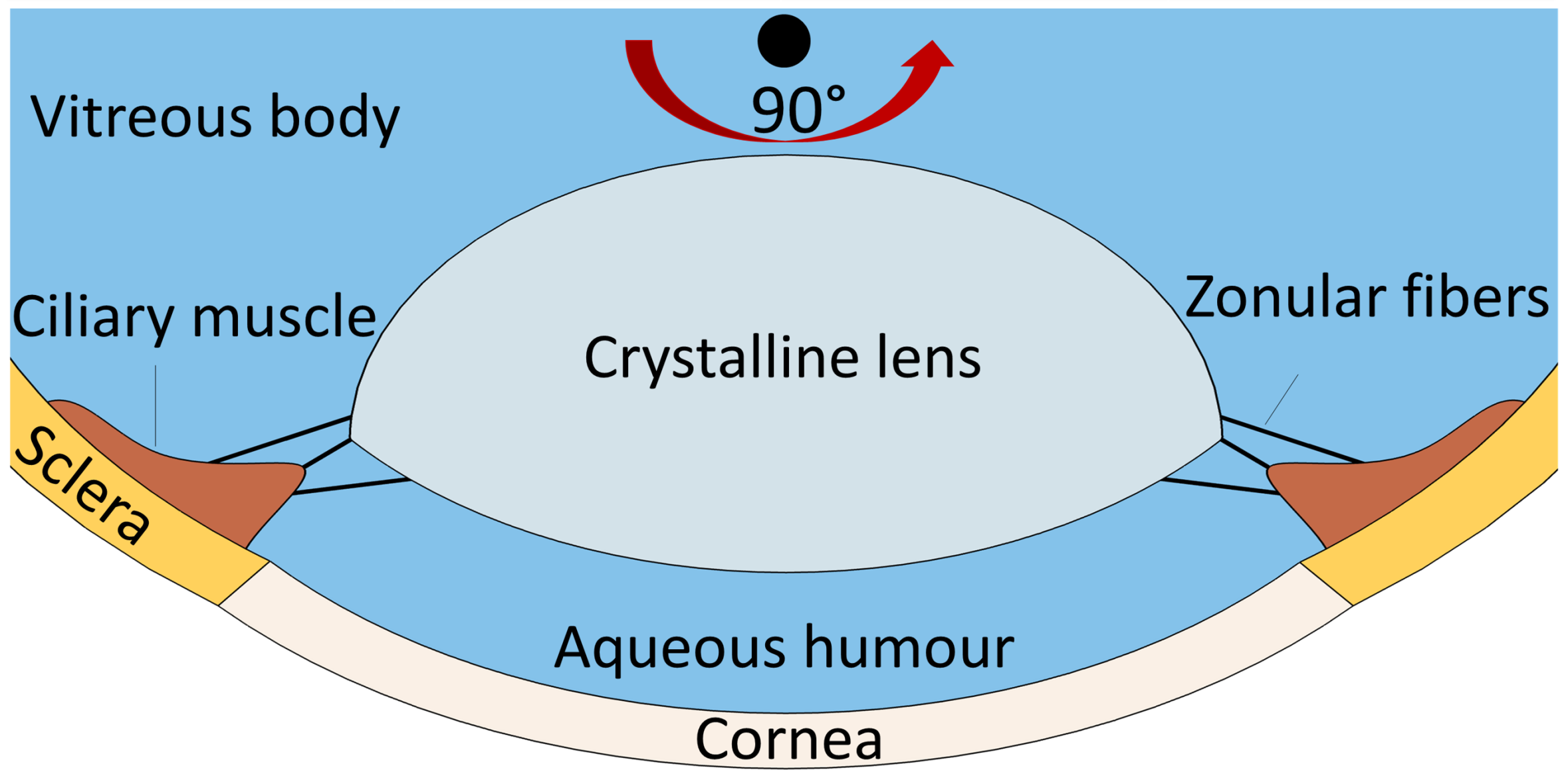

FIGURE 1. Geometry and material properties of porcine eye.

Methodology

To quantitatively assess the inertial movement of the crystalline lens, a 2-D numerical model of a porcine eye was developed using COMSOL Multiphysics®. This model simulates the effect of intraocular pressure as a fluid, encompassing the influential components that play a significant role in the biomechanics of the eye (Figure 1). It is assumed that all the structures within this model exhibit linear elasticity.

Similarly to the ex vivo experiment, the eyeball rotated 90° around its vertical symmetry axis. Subsequently, the output data from the Finite Element Method (FEM) simulations, which includes the recorded coordinate positions of all optical surfaces, was transferred to Zemax OpticStudio® software to analyze the influence of the lens interial motion on the wobbling trajectory in terms of Purkinje performance.

Results

Figure 2a illustrates the changes in the position of the lens apex relative to the center of the cornea (PIV-PI) over a period of time, with data obtained from experiments and modeling. It appears that the lens initially exhibits some overshooting in its movement, but eventually stabilizes. This stabilization can be likely associated to the damping behaviour of the zonules and ciliary body (Figure 2b). The observation suggests that the damping system plays a crucial role in absorbing forces acting on the lens, potentially contributing to the improvement of image quality. This implies that the damping system helps the lens to maintain a stable position, which is essential for clear vision.

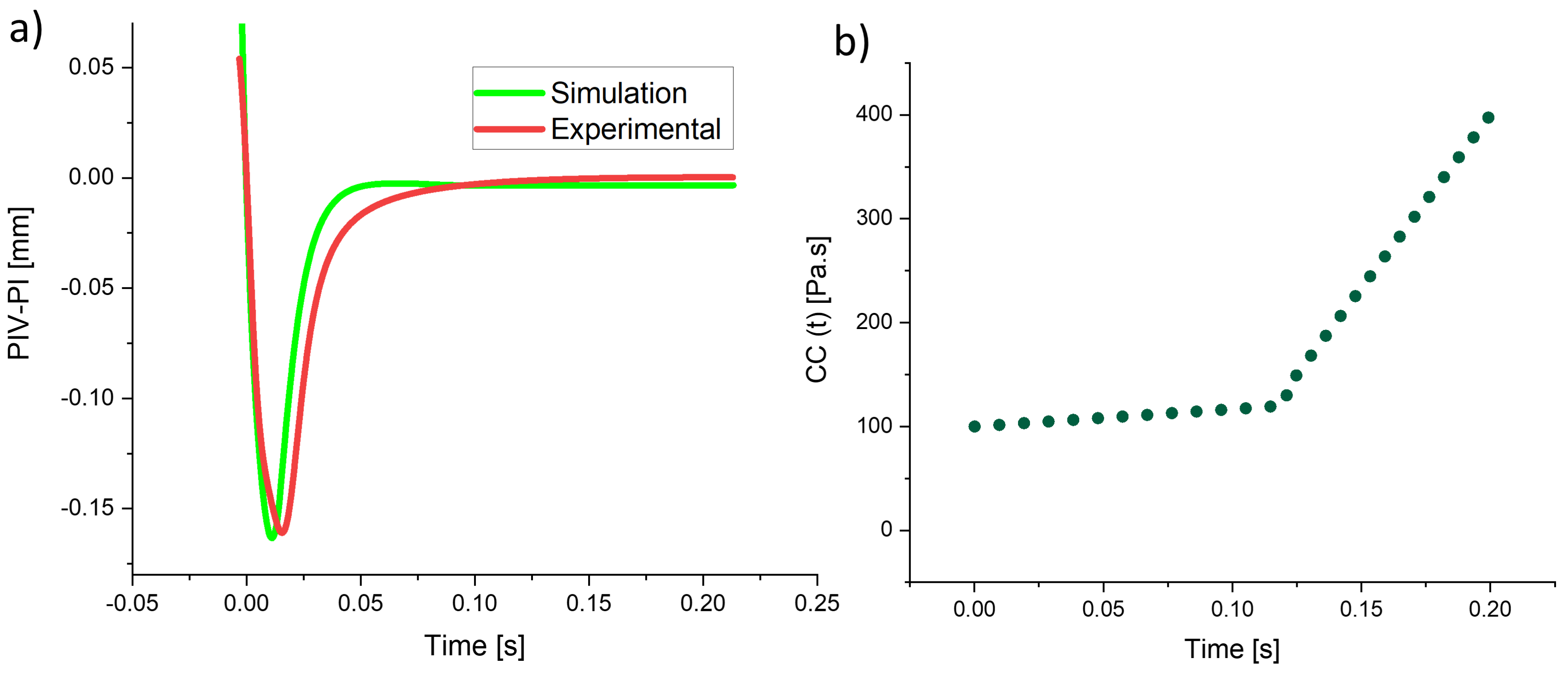

FIGURE 2. a) Overshooting magnitude in the experimental and simulation results, b) Estimated damping function.

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