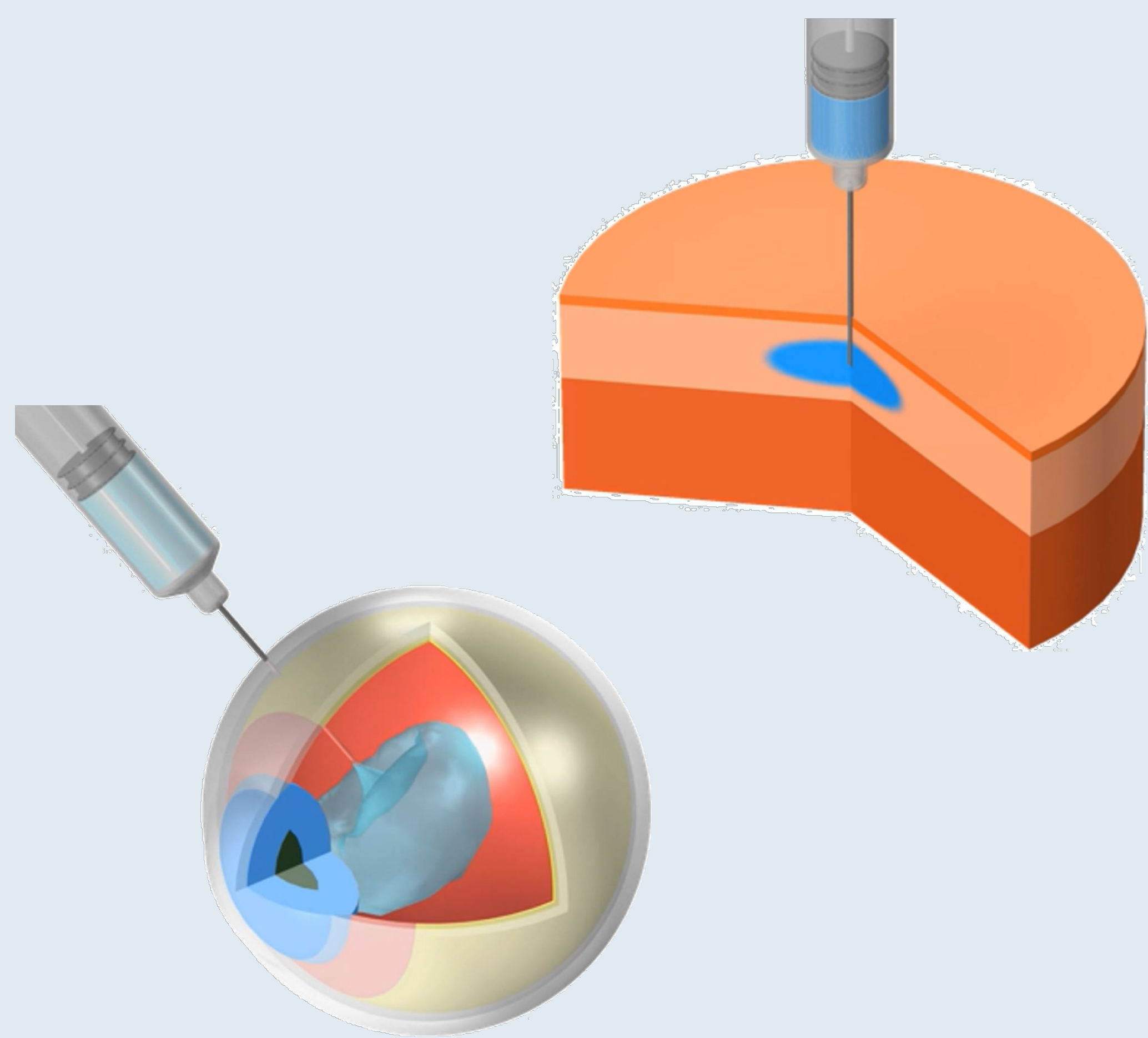




Multiphysics Simulation of Subcutaneous and Intravitreal Injection

Coupled CFD, solid mechanics, and species transport simulations in COMSOL Multiphysics® predict injection force, delivery time, and drug bolus formation, guiding the design of prefilled syringes and autoinjectors for subcutaneous and intravitreal drug delivery.

Matthew Hancock, Ph.D.
Joseph Barakat, Ph.D.

mhancock@veryst.com
jbarakat@veryst.com

Veryst Engineering
Needham, MA, USA

Abstract

Subcutaneous (SC) and intravitreal (IVT) injections are critical routes of administration for targeted drug therapy, each presenting distinct engineering challenges for combination products such as prefilled syringes and autoinjectors. Successful SC injection requires optimizing dose volume, flow rate, and needle gauge to ensure patient comfort and effective drug uptake, while IVT injection demands precise volumetric control and careful management of injection rate to protect delicate retinal tissues, maintain safe intraocular pressure (IOP), and accurately target specific intraocular structures.

Predicting device performance and patient outcomes for both routes remains challenging, as even small changes to injectate formulation or device geometry can substantially affect delivery time, injection force, and drug distribution. In this poster, we present multiphysics CFD simulations of SC and IVT injection using COMSOL Multiphysics®, coupling fluid flow, tissue mechanics, and species transport to predict key performance metrics. Our results enable engineers to make informed device and protocol design decisions that enhance delivery reliability, patient comfort, and safety.

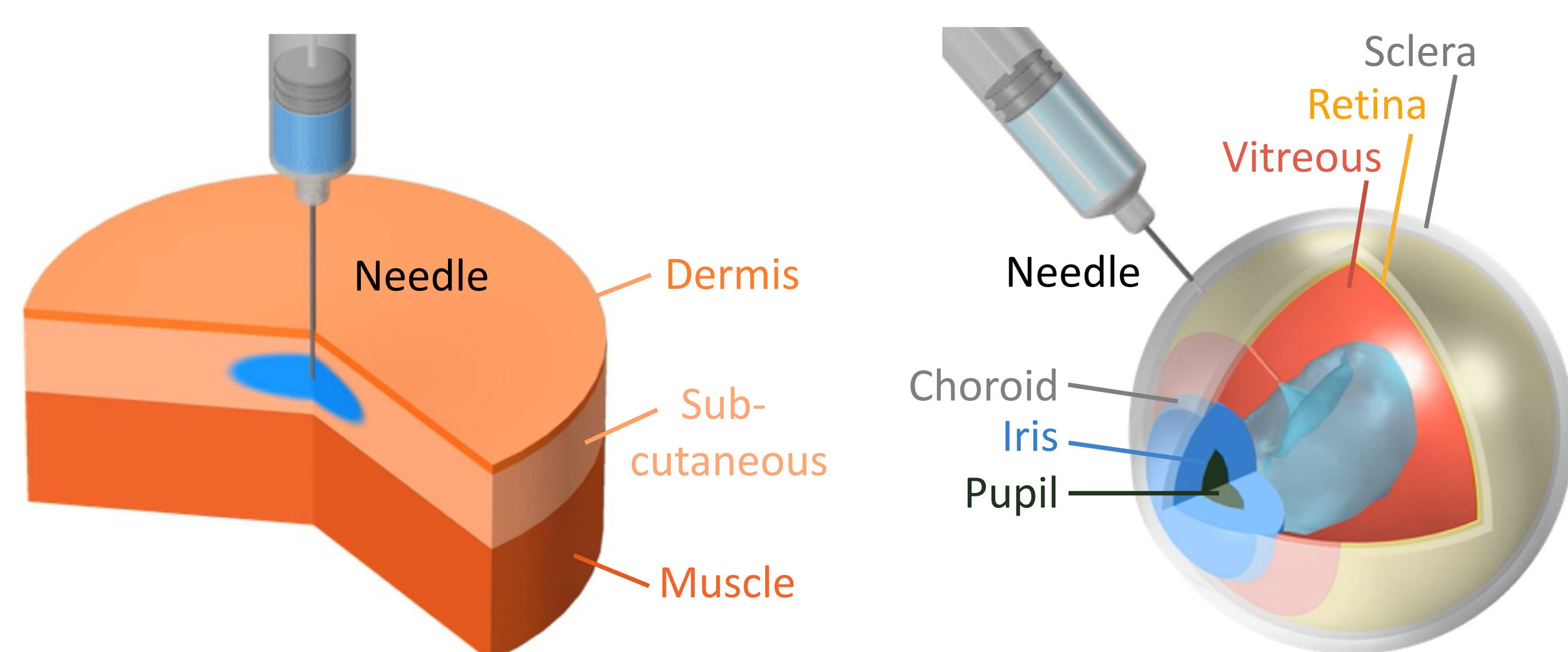


FIGURE 1. COMSOL Multiphysics® simulations of subcutaneous injection (left) and intravitreal injection (right).

Figure 1 shows representative simulations of SC and IVT injection. For SC injection at a flow rate of 0.1 mL/s and injected volume of 2 mL, the model predicts an ellipsoidal drug bolus shape governed by the coupled porous flow and tissue deformation. For IVT injection at 2 mL/min, the injected drug produces a characteristic mushroom-shaped bolus within the vitreous, reflecting momentum-driven jet penetration into a viscous medium.

Figure 2 quantifies bleb height evolution during and after SC injection. Bleb height rises as fluid accumulates locally beneath the skin, then gradually recedes as the drug disperses into surrounding tissue. At high flow rates (>10 mL/min), delivery forces may exceed tens of Newtons, and at large volumes (>10 mL), delivery times can extend to minutes—both important constraints for device and protocol design.

Figure 3 shows predicted drug bolus evolution within the vitreous for IVT injection. At higher flow rates, the injected jet penetrates deeper, increasing the risk of transient IOP elevations near sensitive retinal tissue. These models support parametric studies of needle gauge, flow rate, and formulation viscosity to guide device and protocol optimization while maximizing efficacy and patient comfort. Because the liquid analog does not fully capture the viscoelastic nature of native vitreous, experimental validation remains important to ensure predictive accuracy.

Methodology & Results

For SC injection, we coupled the Porous Media Flow, Solid Mechanics, and Transport of Diluted Species interfaces to model three-dimensional drug dispersion in the subcutaneous tissue. Injected fluid induces local tissue swelling that alters porosity and permeability, which in turn affects the speed, spread, and uptake of injected drug. For IVT injection, we used the Laminar Flow and Transport of Diluted Species interfaces to model needle-based injection into the vitreous humor, predicting injection force, delivery time, IOP changes, and drug bolus evolution.

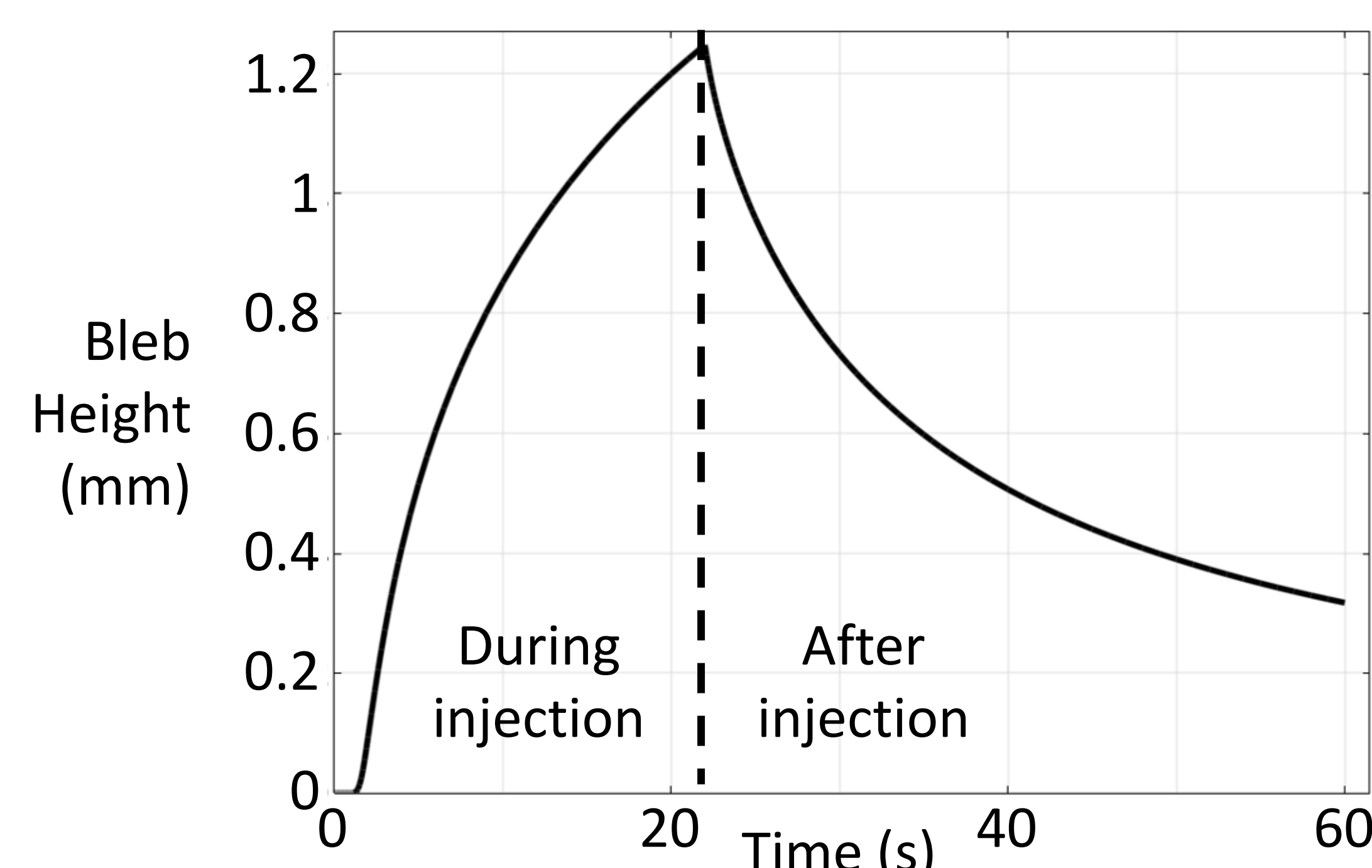


FIGURE 2. Predicted bleb height during and after subcutaneous injection.

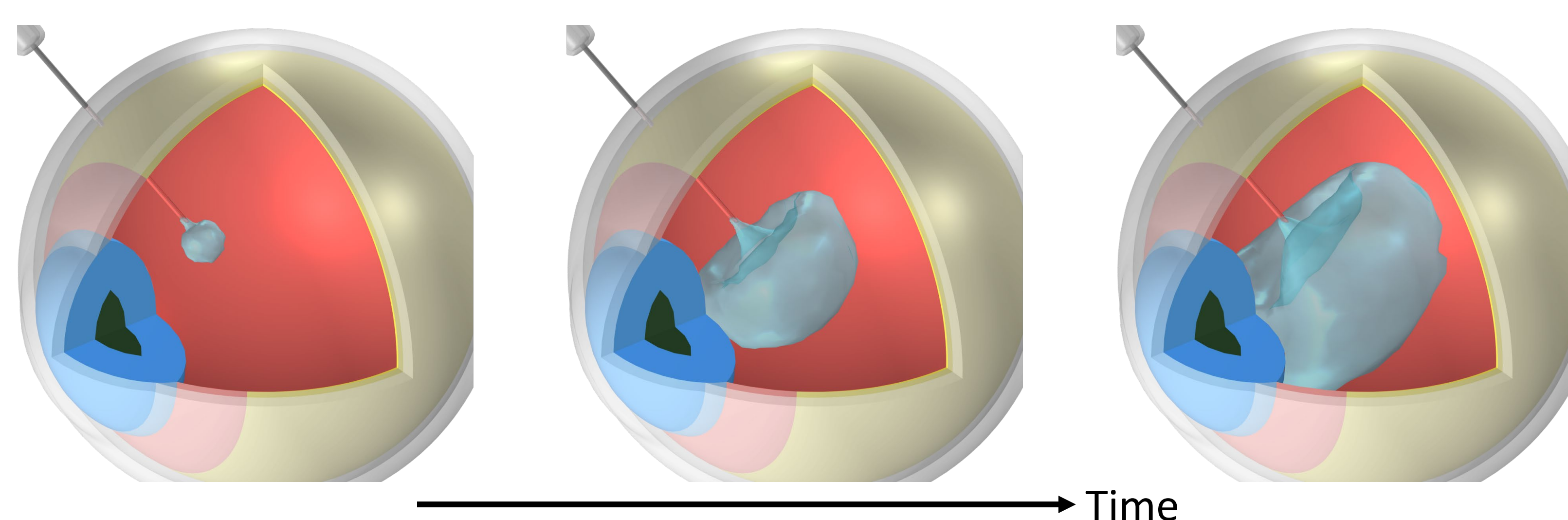


FIGURE 3. Predicted drug bolus evolution within the vitreous humor during intravitreal injection.