Heparin Dispersion And Retention Following Injection Of Locking Fluid In A Hemodialysis Catheter

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Abstract

Hemodialysis catheter lumens are routinely locked with heparin solution to reduce the risk of intra-luminal thrombus formation between treatment sessions. The lock volume infused is chosen to be the volume of the lumen, assuming no significant fraction of the heparin dose reaches the patient. Injection time and vessel blood flow may influence heparin retention and diffusion from the catheter ports, respectively, but this had not been studied. This study models aspects of heparin dispersion and retention using COMSOL Multiphysics.

A 3D model of a Mahurkar™ Elite 12 Fr dual-lumen hemodialysis catheter was built as a COMSOL geometry sequence (Fig. 1) using measurements obtained from CT imaging data. The catheter geometry was positioned within a 16 mm diameter cylindrical geometry representing the iliac vein. A user-controlled mesh combining swept and free elements with boundary layer elements was built.

Separate single-phase laminar flow physics interfaces implementing the incompressible Navier-Stokes equations with Newtonian behavior were used to represent the different material properties of blood in the blood vessel, and water (heparin solution) in the infusion lumen, respectively. The convection-diffusion equation was implemented over both fluid domains to model heparin transport using the transport of diluted species interface, with multiphysics coupling.

Boundary conditions included volumetric flow at the inlets to the blood vessel and infusion lumen. The blood vessel outlet condition was pressure of 0 mmHg. The side and distal catheter ports had boundary conditions coupling pressure and velocity between the two fluid domains. The heparin lock solution contained 5,000 units per ml, with an injection volume equal to the lumen volume (0.60 ml), for a total amount of 3,000 units of heparin per injection. The time-dependent segregated solver using the PARDISO direct solver for segregated steps was used with the parametric solver, with time-stepping determined by the automatic Newton feature.

Two studies were completed. An injection study evaluated the instillation of the heparinized locking fluid at injection rates ranging from 1 to 5 seconds using a parameter sweep, representing a range of injection velocities. This study examined the amount of heparin retained in the catheter vs. gaining access to the blood stream at the end of the injection. This study revealed that approximately 2250 of 3000 units were retained, with the remainder reaching the bloodstream (Fig. 2). A shorter injection time resulted in greater heparin retention in the catheter, likely due to improved heparin distribution into the catheter tip.

A retention study evaluated the diffusive loss from the catheter through the side and distal ports following injection. A parametric sweep provided inlet blood flow rates of 0 to 2500 ml/min in 500 ml/min increments. The prior injection study solution at 3 s duration was used as the initialization state for a time-dependent study over 60 minutes. This study revealed a rapid loss of heparin from the lumen over 10 minutes, followed by a stable concentration over 1 hour (Figs 3-4).

Insights from these studies can help inform catheter flushing practices, with on-going studies aimed at defining optimal volumes and concentrations.

Reference

YC Bong, J Walsham . Systemic anticoagulation related to heparin locking of non-tunnelled venous dialysis catheters in intensive care patients. Anaesth Intensive Care. 2016 Jul;44(4):474-6

DM Ivan, T Smith, Allon M. Does the heparin lock concentration affect hemodialysis catheter patency? Clin J Am Soc Nephrol. 2010 Aug;5(8):1458-62.

Figures used in the abstract

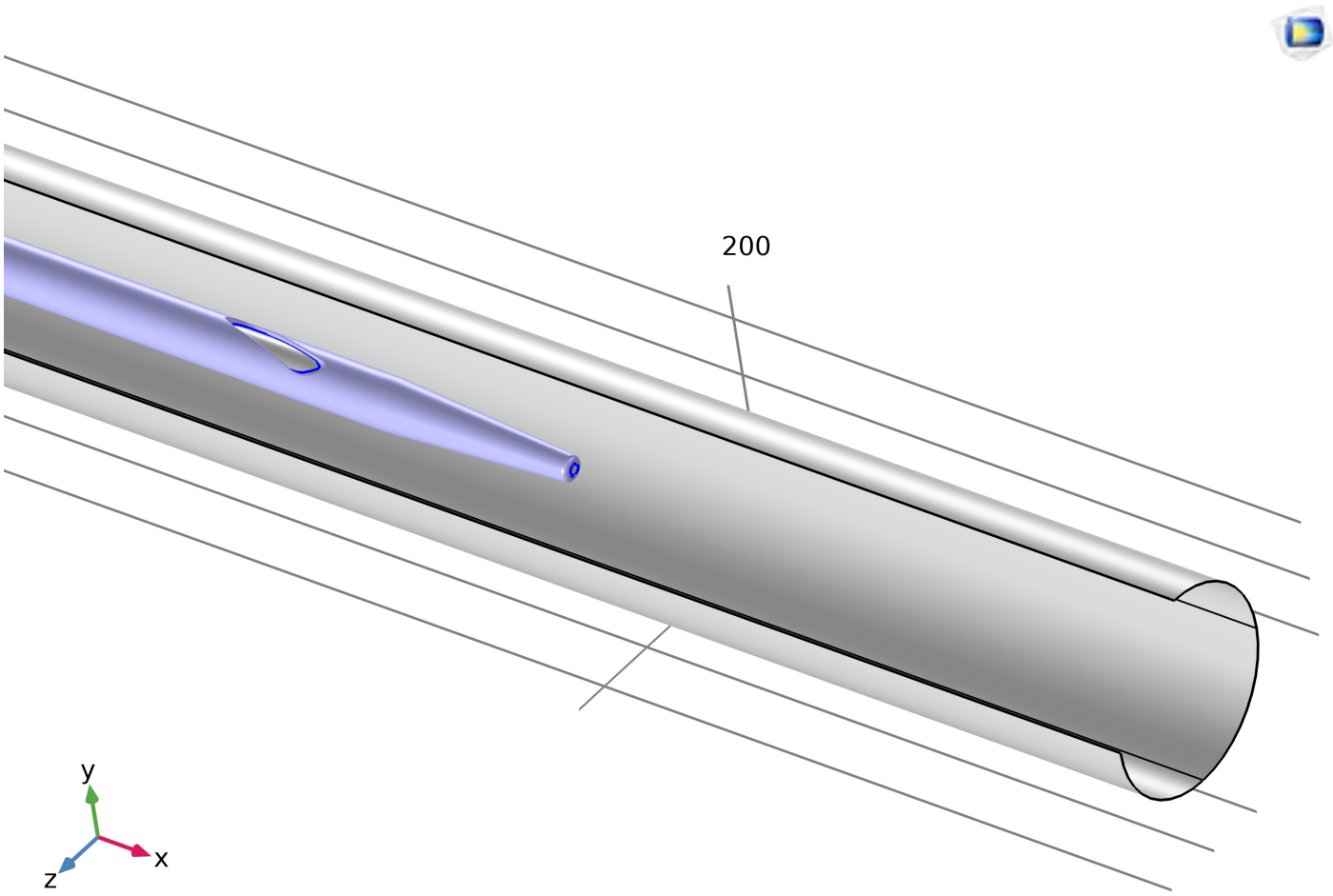

Figure 1 : 3D geometry consisting of hemodialysis catheter within a blood vessel

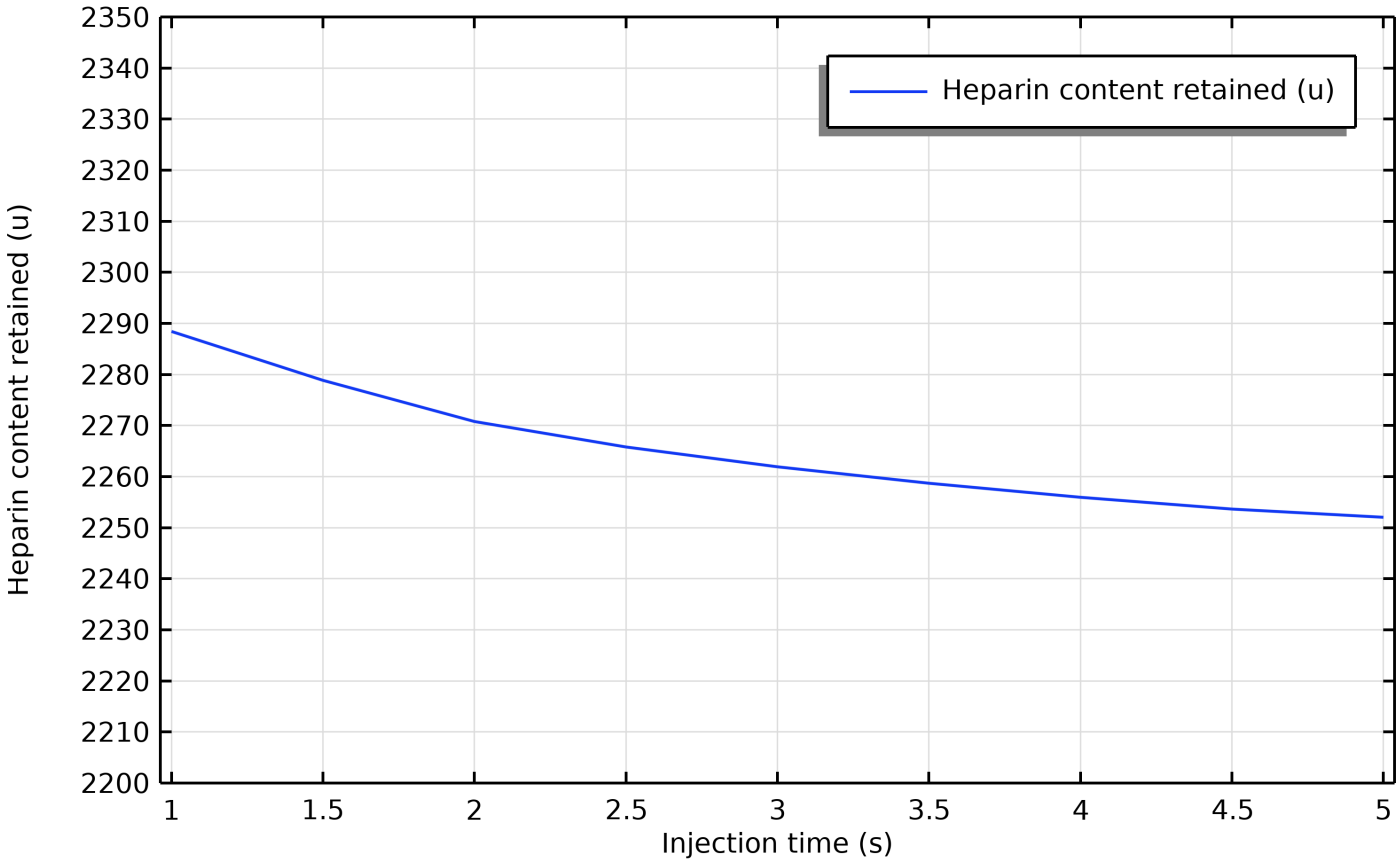

Figure 2 : Heparin content retained within the lumen following injection of lock solution with varying injection times

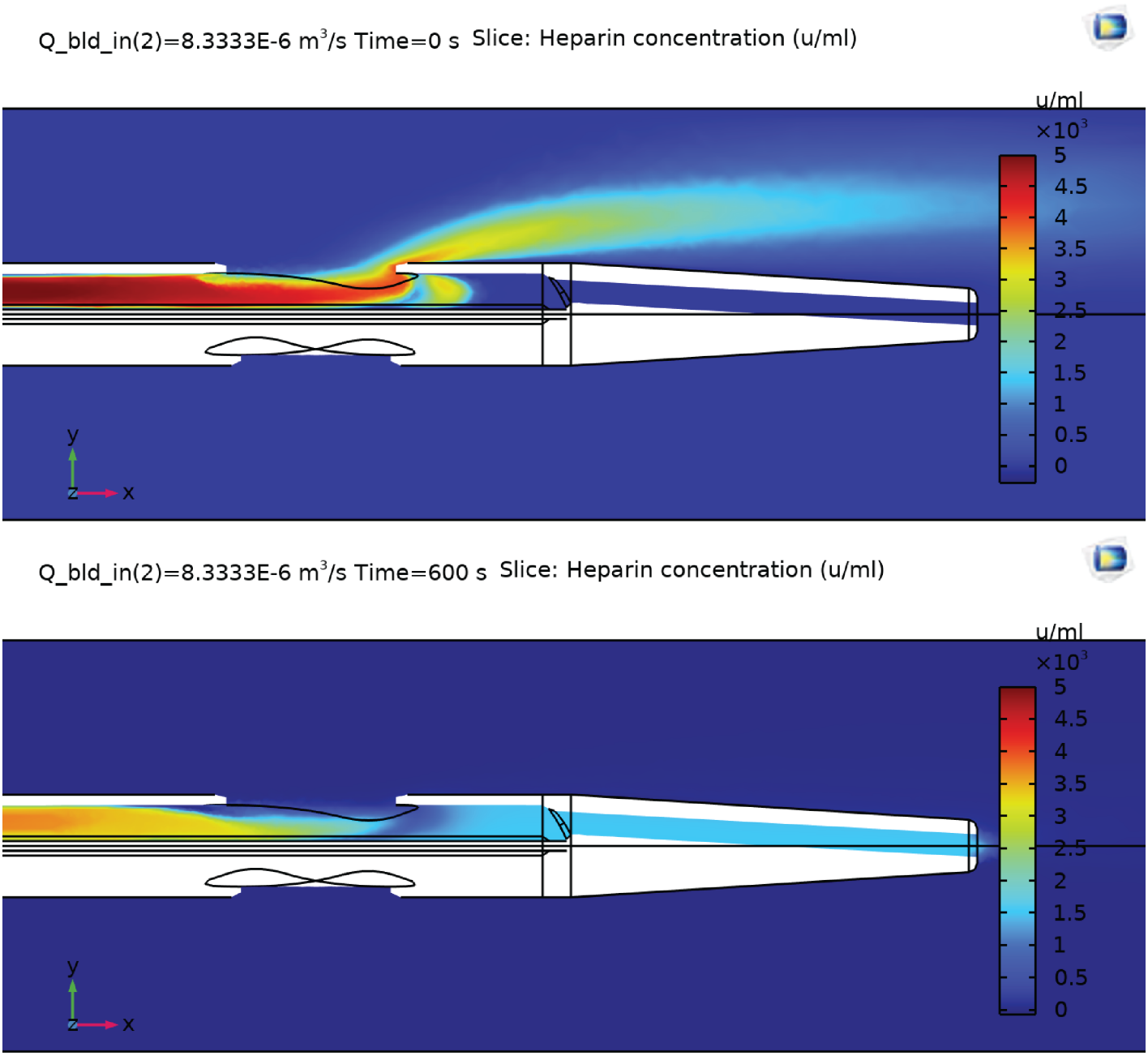

Figure 3 : Visualization of heparin concentration at time = 0 and time = 10 min following injection, with a blood vessel flow of 500 ml/min (left to right)

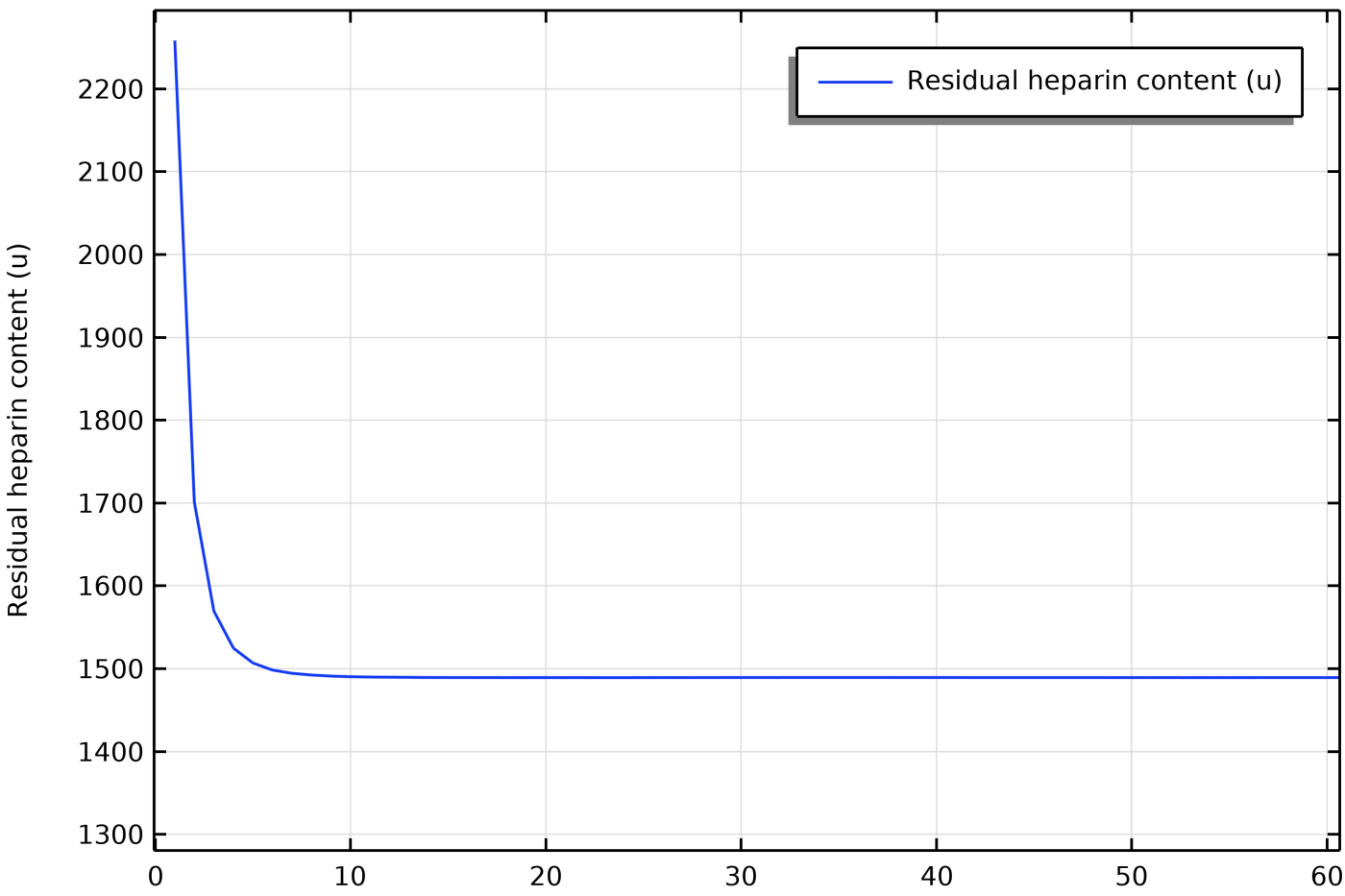

Figure 4 : Plot of heparin retention over the course of 60 minutes following injection, showing a rapid early diffusion from the catheter followed by a near-stable content.