Introduction

Manipulation of extracellular electrolytes is an important part of the management of critically ill patients. Controlled hyperventilation can play a role in the management of intracranial hypertension. The ability to predict CRRT operating parameters and/or results of therapy may prove useful in the application of this therapy. Extracorporeal sodium during CRRT is determined by a number of interrelated factors that make prediction of sodium levels non-trivial, and include sodium concentrations and infusion rates of Na citrate anticoagulation, replacement fluid, dialysate, intravascular fluids and urine. In addition, volume of sodium distribution, water balance between intracellular and extracellular compartments, and convective and diffusive clearance by the hemofilter play additional important roles. The extracorporal exchange of sodium is complex, depending on the interactions of blood flow, ultrafiltration rate, dialysate rate, intraluminal and membrane diffusion, protein concentration polarization, and others. A multiscale mathematical model, which incorporates model features based on vastly different physical scales, previously developed for citrate balance (CRRT 2012) was extended to include sodium compartment transport, preserving the principles of hemofilter hollow fiber transport (micron scale) while including the dynamics of sodium, citrate and bicarbonate distribution and metabolism in the body (filter scale).

Finite Element Hollow Fiber Model

The hollow fiber model was adapted from a finite element model previously presented (CRRT 2012) by extending it to include sodium in addition to citrate and bicarbonate, and is briefly described here. The hollow fiber unit was modeled as a 2-dimensional axi-symmetric geometry corresponding to the dimensions of the M100 hollow fiber length.

Moment balance

The blood phase and dialysate phase momentum balances are described by the incompressible Navier-Stokes equations, where u is the velocity vector, p is pressure,  is density, and  is dynamic viscosity:

The membrane momentum balance is described by the Brinkman equations for porous flow, where k is the permeability coefficient, and f is osmotic pressure:

Diffusion coefficients for solutes were calculated from equations in Fournier (1999). A separate mass balance was established for protein in the blood phase. Plasma osmotic pressure is calculated from the Landis-Pappenheimer equation, local hematocrit is calculated from changes in plasma volume, and local plasma and blood viscosity are calculated from the approach by Merrill.

Boundary conditions

Boundary conditions for blood and dialysate inlet and outlet were set to represent experimental conditions of blood flow, dialysate flow, and circuit pressures. At the blood-membrane boundary, flux and pressure were conserved, protein flux was zero, and the concentration gradient for solutes was determined by the sieving coefficient, where  is the Flawman-Darby coefficient:

Sodium and citrate/bicarbonate dynamics were each represented by two compartment (ECF/ICF and central/peripheral) models, respectively, with distribution, metabolism and elimination using ordinary differential equations. The model is based on established sodium models (Manni 2000) and citrate and bicarbonate dynamics (Kornberg 1952) and Kramer (2003).