Modelling the Response of Microdialysis Probes in Glucose Concentration Measurement

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Abstract

Introduction:

Microdialysis is a technique of continuous glucose monitoring currently used in the glycemic control of type 1 diabetic patients. Figure 1 shows two typical configurations. In microdialysis, a saline serum is perfused in a microdialysis probe. Glucose pass from the plasmatic fluid through the porous membrane. The glucose concentration in the obtained dialysate is measured by an external analytical device [1].

This preliminary work aimed to obtain a model to relate glucose concentration in blood with the concentration of the dialysate for both types of microdialysis probes. Some model assumptions can be found in [2-4]. The model considers different concentric layers in the r-coordinate (Figure 2): The interstitial zone is formed by normal tissue and contains plasmatic interstitial fluid that receives glucose with the capillary network. Different concentration in the external boundaries is taken according to the depth of penetration. The inflammation or trauma zone is included accounts for reaction of the organism against the probe and insertion trauma, with properties that vary in the long term. The membrane has permselectivity properties previously obtainable from in vitro experiments. The inner layer is the liquid perfused to the probe.

Use of COMSOL Multiphysics®:

A simplified 2D axis-symmetric geometry was considered after having related the conditions in the depth-coordinate with the z-coordinate of the model. The glucose transport inside the tube used the Laminar Flow interface coupled with the Transport of Diluted Species interface including convection. The membrane was modeled by the Transport of Diluted Species interface. The glucose transport through the inflammation and interstitial layer were modeled with the Transport of Diluted Species interface. The interstitial domain used an effective diffusion coefficient to account for the convection in the plasmatic fluid. Time Dependent solvers were used to analyze step changes and Stationary solvers for the parametric studies.

Results:

Parametric studies were performed to study the effects of perfusion flow, membrane resistance, or evolution of the transport resistance of the inflammatory zone. The results showed that glucose recovery was approximately proportional to the inverse of the perfusion flow and approximately independent of glucose concentration in blood. Figure 3 and 4 show results obtained for a microdialysis probe of diameter 22 µm, inner cannula of diameter 15 µm, and length 15 mm. Figure 3 shows the exiting glucose recovery referred to blood concentration at perfusion rates between 100 to 150 µL/h. Figure 4 shows the evolution of the average outlet concentration after a change of the perfusion rate from 120 to 150 µL/h.

Conclusion:

The developed microdialysis model can be used to improve performance of continuous glucose monitors by selection of optimal operating conditions (perfusion rate, depth of penetration ...). Besides, the model can also be used to better understand the behavior of the microdialysis probe under different situations (tissue structure, changes in the resistance as a consequence of the inflammatory evolution ...) explaining variability. Besides its capacity to study the detection of components in tissues like glucose; with small changes, the model can be adapted to study drug delivery by microdialysis.

Reference

[1] Y. Hashiguchi, Development of a miniaturized glucose monitoring system by combining a needle-type glucose sensor with microdialysis sampling method, Diabetes Care, 17 (1994)
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[3] K. Kretsos, G.B. Kasting, A geometrical model of dermal capillary clearance, Mathematical Biosciences, 208, 430–453 (2007)
[4] K.C. Chen, Effects of tissue trauma on the characteristics of microdialysis zero-net-flux method sampling neurotransmitters, Journal of Theoretical Biology, 238, 863–881(2006)

Figures used in the abstract

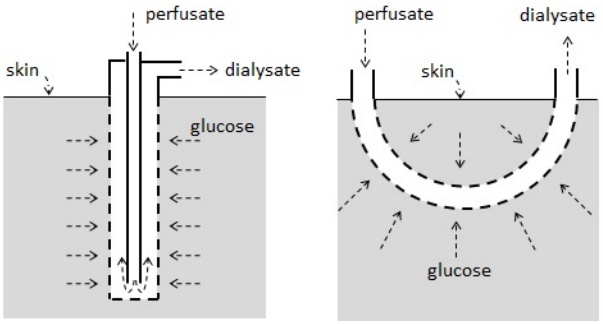

Figure 1: Microdialysis configurations studied.

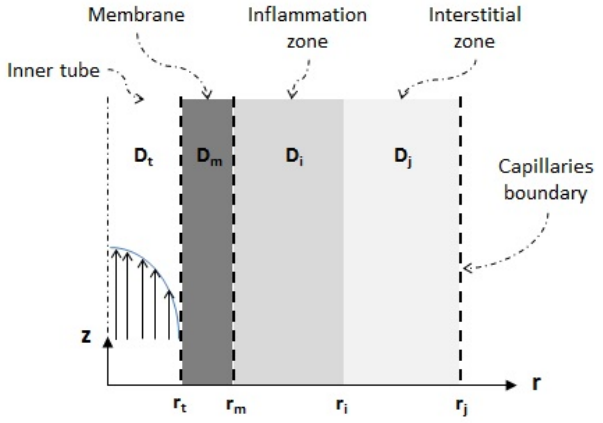

Figure 2: Schematic representation of the zones considered in the model.

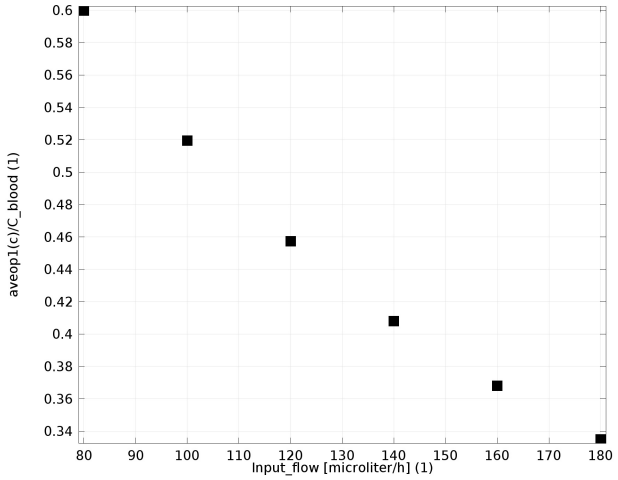

Figure 3: Glucose recovery versus perfusion rate.

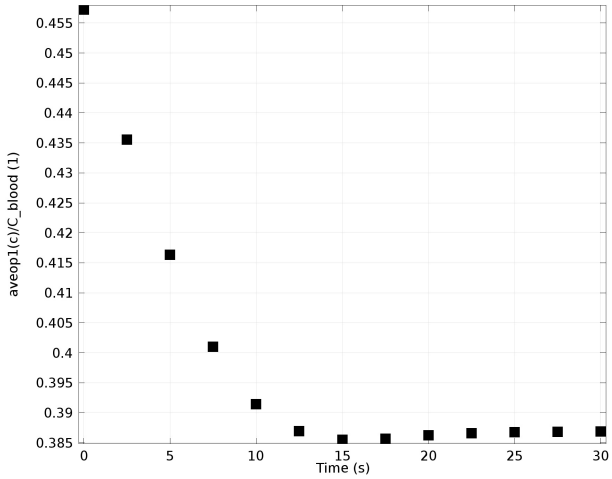

Figure 4: Evolution of output glucose concentration after a step change in the perfusion rate from 120 to 150 µL/h.