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Mass transport analysis in linear microdialysis probes utilizing structural characterization technique

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Abstract

Microdialysis is a separation technique widely used for sampling and monitoring purposes. Microdialysis requires a (microdialysis) probe to be inserted to the designated area of study. Separation procedure is completed by using a selective semi-permeable membrane attached to the microdialysis proe. Despite being a well-established technique, there are still issues regarding the performance of the microdialysis probe. The biggest issue is arguably that the concentration of solutes collected via microdialysis sampling represents only 20-30% of the original concentration from the sampling site. This issue can be resolved by understanding mass transport phenomena within the microdialysis probe and its surroundings. One straightforward, yet sustainable way to analyze mass transport is through the use of computational modelling. In this paper, a mathematical framework, representing glucose recovery from a quiescent media using a microdialysis probe of linear design was described. Governing equations, boundary conditions and operational parameters were justifiably selected. Different diffusion coefficients were used to describe the mass transport through the quiescent media, semi-permeable membrane and the probe‘s lumen. Subsequently, the influence of some identified parameters, on the overall recovery is examined. Scanning electron microscopy imaging was used to study the physical characteristics of the microdialysis membrane, thus being utilized to estimate the

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diffusion coefficient values. The impact of using different diffusion coefficient values on the overall recovery was also discussed.

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Nomenclature

c	concentration of solute collected from microdialysis sampling (mol m^{-3})
c_g	concentration of glucose at sampling site (mol m^{-3})
c_o	concentration of solute at microdialysis probe inlet (mol m^{-3})
c_s	concentration of solute at sampling site (mol m^{-3})
D	diffusion coefficient / diffusivity (m^2 s^{-1})
D_{AB}	molecular diffusion of a solute A in medium B (m^2 s^{-1})
D_g	diffusivity of glucose in water (m^2 s^{-1})
D_m	D_{AB} as hindered by the semi-permeable membrane (m^2 s^{-1})
ECF	extracellular fluid
F	external forces acting on fluid
l_m	length of semipermeable membrane (m)
MWCO	molecular weight cut off
NS	Navier-Stokes
PI	probe interior
PSA	probe surrounding area
R	inner radius of microdialysis probe (m)
R_p	average radius of glucose molecule (m)
R_s	radius of pore at the surface of membrane (m)
RR	relative recovery
u	fluid velocity (m s^{-1})
u_{ns}	fluid velocity in radial (horizontal) direction (m s^{-1})
V	flow rate of perfuse solution in microdialysis probe (L min^{-1})
v_o	velocity of perfuse solution in microdialysis probe (m s^{-1})
v_{ns}	fluid velocity in axial (vertical) direction (m s^{-1})
α	hindrance factor of membrane
i_m	thickness of semipermeable membrane (m)
i_c	thickness of connecting pipes' wall (m)
ε_p	porosity of membrane (%)
η	dynamic viscosity of perfuse solution (kg m^{-1} s^{-1})
$\xi_{d,i}$	hindrance factor for diffusion
ρ	density of perfuse solution (kg m^{-3})
τ	tortuosity of membrane

1. Introduction

1.1. Introduction

Microdialysis is a membrane based separation technique introduced in the 1970's. This technique is most commonly used for sampling neurotransmitters as well as other diffusible solutes from extracellular space in tissues for pharmacokinetic and neuropharmacological studies[1]. When used for in vivo studies, a probe (commonly known as microdialysis probe) will be inserted into the tissue area of the specimen. With respect to this, microdialysis is considered to be a minimally invasive technique. Microdialysis applications are not limited to in vivo studies. Various researchers have reported using microdialysis technique for in vitro studies as well[1-3]. Apart