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Rearranging the Nernst Equation to Make a Dosage-Controllable Membrane Delivery System

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ABSTRACT:

Electrochemically induced or augmented membrane-based drug delivery is a well-known art. However, it is often difficult to obtain a quantifiable relationship between quantity of drug delivered and voltage or current used. Described here is an alternative way of doing electrochemically induced membrane drug delivery where the membrane is smart and turns itself off when the desired amount of drug has been delivered. Furthermore, the amount of drug delivered at shut off is exactly quantifiable by a rearranged (exponential) form of the well-known Nernst concentration-cell equation. We demonstrate this concept with a simple prototype system based on a commercial anion exchange membrane. For this system, the drug molecule must be an anion, and nitrate was used as the surrogate drug anion here.

Keywords: Anion-exchange membrane, drug delivery, transference numbers, membrane voltage, Nernst equation

1. Introduction

Synthetic membranes are used commercially as drug delivery vehicles, often in the form of patches applied to the skin.[1,2] Transport of the drug from the membrane may occur by simple diffusion,[3,4] ion exchange,[5] or by passing a current through the membrane.[1,3,4] If the drug is charged, passing a current might enhance the flux because of electrical migration. However, the amount of enhancement achieved would depend on what fraction of the current is carried by the drug ion, and flux might be augmented or decreased by electroosmotic flow.[6-8] Hence, while electrochemistry has proven useful in membrane-based drug delivery, obtaining a quantifiable relationship between amount of drug delivered and current or applied voltage is problematic.[1,9,10]

We describe here an alternative way of doing electrochemically induced membrane drug delivery where the membrane is smart and turns itself off when the desired amount of drug has been delivered. Furthermore, the quantity of drug delivered at shut off is exactly quantifiable. We demonstrate this concept with a simple prototype system (**Fig. 1**) based on a commercial anion exchange membrane (AEM). For this system, the drug molecule must be an anion, and nitrate was used as the surrogate drug anion here.

We show experimentally that the membrane does, indeed, turn itself off, *i.e.* nitrate delivery stops, when a known and quantifiable amount of NO_3^- has been delivered. This effect is based on a simple rearrangement of the well-known concentration-cell form of the Nernst equation.[11] We provide the theoretical and mathematical bases that underlie this proposed delivery method.

2. Theory

The AEM separates a feed solution containing the drug anion, in this case NO_3^-, from a receiver solution, initially devoid of this anion (**Fig. 1**). A silver wire electrode, is immersed into each solution. When a voltage, E_{app}, is applied across this cell such that the receiver solution contains the anode, NO_3^- will be transported from feed to receiver solutions, thus delivering the drug (**Fig. 1**). This is because the anode (receiver) half reaction

$$Ag \rightarrow Ag^+ + e^- \qquad (1)$$

creates the need for additional NO_3^- to maintain electroneutrality in the receiver solution. NO_3^- delivery also maintains electroneutrality in the feed solution because the cathode half reaction is the reverse of Eq. **(1)** and removes Ag^+.

However, if the membrane transports only nitrate and no other anion or cation, delivery will spontaneously stop when a precisely defined amount of nitrate has been delivered. While this prediction may seem counter intuitive, it stems from the well-known concentration-cell form of the Nernst equation.[11]

$$E_m = \frac{RT}{zF} ln \frac{a_r}{a_f} \qquad (2)$$

where R, T, z and F are the gas constant, temperature, charge of the drug ion and Faraday's constant, respectively. E_m is the equilibrium membrane voltage that develops across the AEM because the activity of the drug anion in

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