Simulation of Transdermal Toxin Expulsion Via Adsorptive Dermal Patch Using COMSOL Multiphysics ®

H. Kwon[1], M. Hess II[1], R. M. Polski[1]

[1]Andrews University, Berrien Springs, MI, USA

Abstract

Introduction:

Human skin is a highly complex organ made of multiple composite layers, including the subcutaneous tissue, the dermis, and the epidermis. These layers contain ducts and pores that allow substances to pass into or out of the body[1]. Mathematical skin models play an important role in fields such as transdermal drug delivery and assessment of dermal exposure to industrial chemicals. Extensive research has been conducted using the skin as a means of moderating and controlling drug delivery through transdermal adsorption[2]. Little effort has been made, however, to view the skin as a permeable layer to expel waste chemicals or toxins from the body. Activated charcoal has an extraordinarily large surface area and pore volume, making it suitable for a wide range of applications, including toxin removal[3]. In this work, we focused on topical application of charcoal poultices or dermal patches that are used for cleansing the body by stimulating circulation and drawing out impurities thorough transdermal adsorption[4]. We developed a two-dimensional computational skin model to evaluate removal of toxins through skin as permeable layers. The simplified skin model consists of the dermis and epidermis layers as diffusive layers and endotoxins of inflammation, as a point source (Figure 1). The results were compared with and without the aid of an adsorptive topical dermal patch.

Use of COMSOL Multiphysics®:

We developed a 2-dimensional multilayered skin model with a topical adsorptive layer. The adsorptive layer was modeled as an infinitely thin layer and the intrinsic inhomogeneity of the skin layers was not considered. We modeled the mass transport by diffusion using the transient diffusion equation. The toxin was modeled as originating from a point source beneath the dermis, lasting several hours. Charcoal adsorption of the toxin was modeled using pseudo first-order reaction kinetics[5].

Results:

A large difference was seen between the patch-less model and a model with even a very small value of kads. Figure 2 shows plots of the average concentration over time with no adsorptive

layer, with a low dose, and with a high dose. As shown in the figure, a small rate of adsorption produced a significant decrease in concentration over time compared to no adsorption. Figure 3 shows the concentration gradient over the skin cross-section for the same three models after approximately 4 hours. Influencing factors such as contact area, skin variations, and so on affect the rate of adsorption.

Conclusion:

This study represents what is to our knowledge the first attempt to create a mathematical model of topical application of adsorptive layers to draw out impurities through permeable skin layers. For many years, we have known of the efficacy of dermal application of activated charcoal only clinically, but a scientific model or explanation has been lacking. Although several assumptions were used to make the otherwise complex model simple, the model successfully showed how the concentration of a toxin in the skin can be reduced significantly faster with an external, topical adsorptive patch.

Reference

1. Mitragotri, S.; Anissimov, Y.G.; Bunge, A.L.; Frasch, H.F.; Guy, R.H.; Hadgraft, J.; Kasting, G.B.; Lane, M.E.; Roberts, M.S., Mathematical models of skin permeability: An overview. Int. J. Pharm. 2011, 418, 115-119.
2. Corish, J.; Corrigan, O.I., Transdermal diffusion of drug molecules. Journal of the Chemical Society, Faraday Transactions 1990, 86, 1317-1321.
3. Olsen, K., Activated charcoal for acute poisoning: One toxicologist’s journey. J. Med. Toxicol. 2010, 2010, 190-198.
4. Ioannou, Z.; Simitzis, J., Adsorption of methylene blue dye onto activated carbons based on agricultural by-products: Equilibrium and kinetic studies. Water Science & Technology 2013, 67, 1688-1694.
5. Malarvizhi, R.; Sulochana, N., Sorption isotherm and kinetic studies of methylene blue uptake onto activated carbon prepared from wood apple shell JOURNAL OF ENVIRONMENTAL PROTECTION SCIENCE 2008, 2, 40-46.

Figures used in the abstract

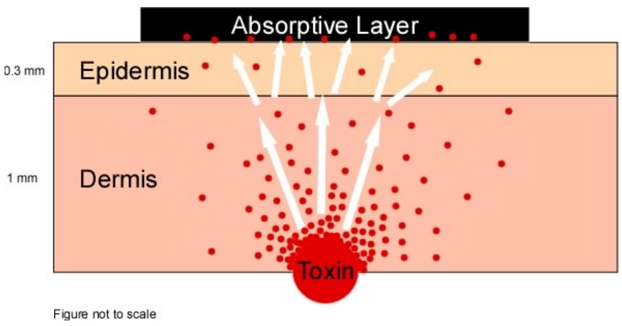

Figure 1: Schematic of 2-D skin model and removal of toxin through topical application of absorptive layer.

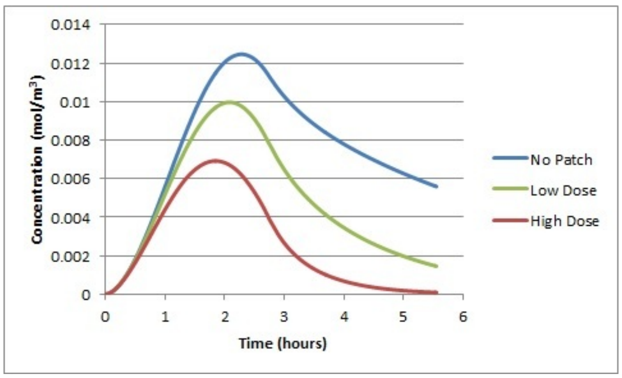

Figure 2: Average concentration with no patch and with low and high doses of charcoal poultice.

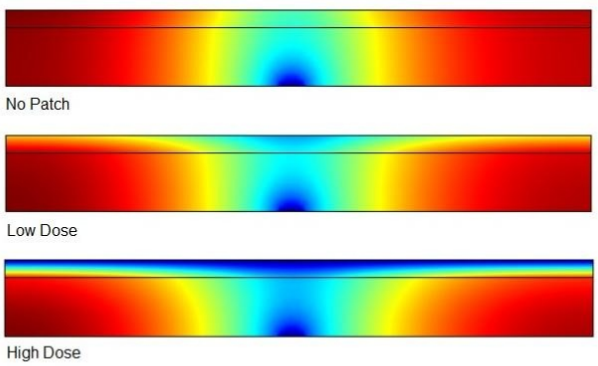

Figure 3: Concentration distribution at time t = 15000.