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Material Characterization Method Development: From Education to Design Optimization

Courtney F. Morgan*[1], Nirupama Kenkare[1], Mackenzie G. Williams[1, 2, 3], Anna Peterson[1, 2, 4] and Daniel M. Williams[1, 2, 5]
[1]Alcon Eye Care Division of Novartis, [2]Georgia Institute of Technology Co-op Program, [3]School of Chemistry & Biochemistry, [4]GT/Emory Department of Biomedical Engineering, [5]School of Chemical and Biomolecular Engineering
*Corresponding author: 11460 Johns Creek Parkway, Duluth, GA 30097
courtney.morgan@cibavision.com

Abstract: Introduction of silicone hydrogel contact lens materials in the 1990s provided eye care professionals with products of unprecedented capability to deliver oxygen to the eye during contact lens wear. Along with this capability come material characteristics that have not been of routine concern traditionally. One such characteristic is the material's permeability to ions. This paper discusses descriptive tools for optimization of an electrical impedance based method of characterizing ion permeability. A physical model consisting of conductive paper with geometric constraints provides the ability to visualize effects from the design on the electric potential fields in the saline. Further, these physical models are useful to validate FEA models that ultimately will be used to arrive at an optimized design.

Keywords: Contact lens, silicon hydrogel, ion permeability, conductive paper.

1. Introduction

Appreciation of phenomena of general importance that requires knowledge across multiple disciplines is difficult to grasp without a great deal of hands-on experience. A way to facilitate understanding is to utilize analogous experiences from one's past and apply them to the new phenomenon. Physical models in conjunction with Finite Element Models provide such possibilities to a team with varied backgrounds to focus expertise on a common goal. Our industrial setting team of scientists and engineers from various disciplines must communicate with machinists, clinicians, and marketing professionals.

The challenge of developing a practical new physical property test method may include the incorporation of a new technology or the introduction of a new application of existing technology, understanding the correlation of the new response to historical methods and optimization of fixture engineering design and materials of construction.

We present our approach to bring to bear the collective efforts of a team diverse in technical background and experience on the development of an impedance measurement of contact lens ion permeability. The basis of our impedance method is transepithelial electrical resistance (TEER). TEER has been applied to assess the health of cells and as a quantitative measure of confluent growth in tissue culture of corneal epithelial cells. We are adapting commercially available TEER equipment (EVOM and EVOM2 Epithelial Voltmeters, World Precision Instruments, Inc., Sarasota, FL) to our contact lens application.

We have constructed physical models relating to two designs of fixtures to hold the electrodes, lens and saline. The physical models consisting of conductive paper and a DC voltage source are also modeled in COMSOL to permit visualization of differences between the designs and the effects of defects such as leaks or bubbles. Comparison of actual electric potential field measurements from the physical models with the COMSOL model predictions can serve as a validation of the FEA model. The validation then paves the way to expand the FEA model to the 3D saline system.

A final point to make is to highlight our use of the proven educational tool of conductive paper to study electric potential fields which has been in freshman physics labs for decades. Our project illustrates how the traditional physics lab could allow students to segue to FEA-Multiphysics in a convenient, tangible way.

2. Use of COMSOL Multiphysics

A potential of 30 VDC was applied to push-pin electrodes in the conductive paper models of the saline chamber profiles. The electric potential was recorded at various points on an XY coordinate plane on the model. The same geometries and electrodes were generated in COMSOL Multiphysics® Ver. 4.2. A triangular mesh was applied to the models. The AC/DC electric currents (ec) physics was used to simulate a 30VDC electric potential through the geometries. Measured and literature values for the conductive paper material properties were used for the COMSOL models.

3. Methods

The material properties used for the conductive paper are:

Electrical conductivity	σ	= 1.33
Relative permittivity	ε_r	= 3.85

Physical models of cross section profiles were made by cutting conductive paper (PK-9025 Conductive Paper, Pasco Scientific, Roseville, CA) at a 2:1 scale. The cut-outs were placed on the cork panel supplied with the conductive paper kit and held in place by the supplied push-pin electrodes. DC voltage from a variable power supply (Model QRD30-1, Sorensen Power Supplies, San Diego, CA). Measurement of field potential was take with a digital voltmeter (Model 179 True RMS Multimeter, Fluke Corp., Everett, WA) using the crosshatch marks preprinted on the paper as reference.

Figure 1 Horizontal tank fixture cross-section in conductive paper.

4. Results

We have examples aiding visualization of a design's impact on electric field gradients emphasizing the concept of design elements. We have also modeled the effects of leaks and the impact of bubbles, the understanding of which is critical to a fixture's practical implementation and utility.

4.1 Design Element Gradient Visualization

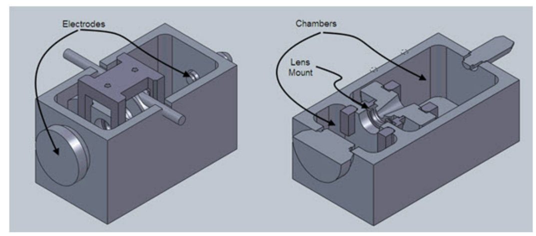

Figure 2 Horizontal tank fixture CAD model.

Figure 2 shows an iteration of a fixture design with a cross sectional view. Two saline chambers are separated by the contact lens membrane in this horizontal tank fixture design. Electrodes are at opposite ends of the two chambers. A systematic study of geometrical design elements affecting the electric potential field through the cross section is presented in

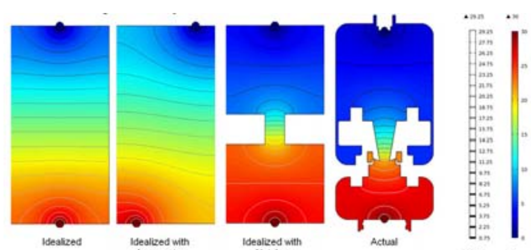

Figure 3 Calculated 2D field maps of horizontal cross sections visualizing geometric design element affects on the electric potential field for the horizontal tank design.

Figure 3. Field maps of the corresponding physical models have been made and are in qualitative agreement.

4.2 Simulated Leaks

A key aspect of a successful lens test fixture implementation is to recognize and prevent leaks in the system and around the lens membrane. Figure 4 shows models with lens membrane resistance in place and a series of leak simulations.

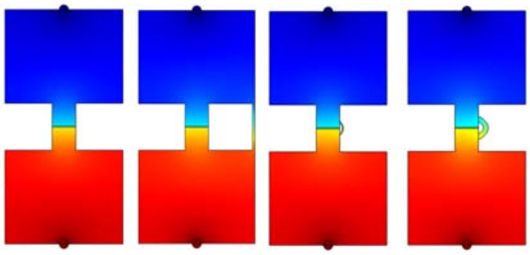

Figure 4 Simulations with idealized geometries (left to right) lens mounted; distant leak; small leak at lens and larger leak at lens.

4.3 Simulated Bubbles

A vertical fixture design utilizing a vacuum lens chuck was tested in prototype (figure 5) and found to be prone to interference from trapped bubbles. This series of simulations is aimed at visualizing the affects from bubbles trapped underneath the lens membrane.

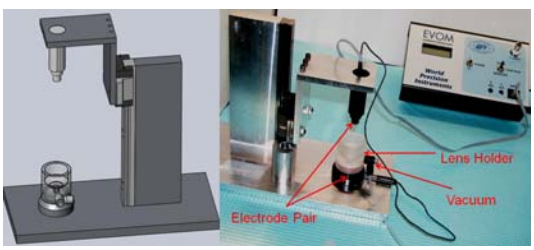

Figure 5 Vertical Fixture CAD modal and prototype.

A series of simulations illustrating the affect of bubbles under the lens surface are presented in figure 6.

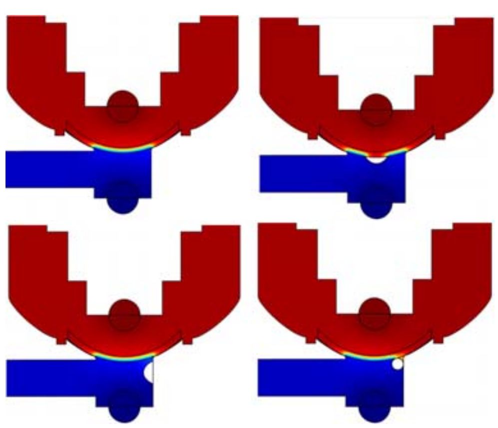

Figure 6 Vertical fixture bubble simulations (clockwise from top left) lens mounted; bubble in center; bubble in corner and bubble along edge.

4.4 Lens Material Measurements

Lens material impedance measurement using the prototype vertical fixture is compared to measurements using a traditional permeability measurement in figure 6. The traditional measurement follows the change in conductivity over time from a system consisting of a membrane separating a "donor cell" with an initial high Cl^-concentration from a "receiver cell" with much lower initial Cl^- concentration.

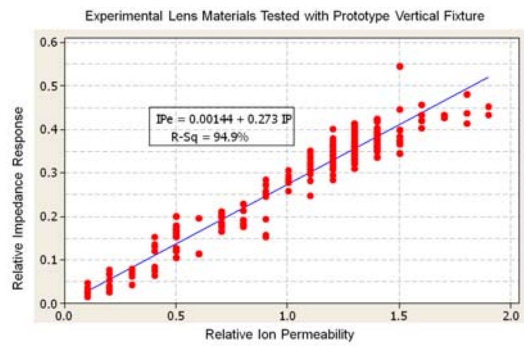

Figure 6 Impedance response of experimental contact lens materials using the prototype vertical fixture compared to a traditional method of characterizing ion permeability.

5. Conclusions

We have expanded our stable of tools to use in developing test methods that will be robust and practical in everyday application. The use of physical models based on simple paper cut-outs provide a tangible link between concept and prototype. The additional benefit of a segue into FEA modeling is, we believe, a significant advantage to individual as well a group potential to contribute to successful designs.

6. References

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