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Development of a Polymeric Eye Model
for Foreign Body Removal

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Abstract

Background: *Removal of a corneal foreign body is a critical skill for optometrists and ophthalmologists to practice, but most students receive minimal and rudimentary training in this area. The aim of this study was to develop a simple polymeric eye model, with embedded metal particles, for teaching foreign body removal.* ***Methods:*** *The eye models were made from 15% weight/volume polyvinyl alcohol, molded into an eyeball shape and embedded with 100- 300-µm size steel particles. The model was tested with 90 third-year optometry students, and a follow-up survey was conducted to rate the usefulness and realism of the model.* ***Results:*** *Of the 33 survey respondents, the majority (70%) thought the model was both useful and realistic.* ***Conclusion:*** *Students can easily use this model to improve their hand-eye coordination and confidence in removing corneal foreign bodies and rust rings under a slit lamp microscope.*

Key Words: *foreign body removal, eye model, polyvinyl alcohol, corneal foreign body removal, FBR*

Introduction

Corneal foreign bodies, such as particulates of metal, glass, wood, plastic or sand, are among the most common causes of ocular injury.[1-3] When left untreated, they can potentially lead to tissue death, infections and vision loss.[1,2] Unfortunately, physicians are often poorly trained in the removal of corneal foreign bodies, which may lead to delayed or suboptimal treatment in the emergency room setting.[3]

The best approach to removing foreign bodies is under slit lamp magnification using a sterile large-gauge needle, followed by removal of the rust ring with an electric burr (AlgerBrush).[1,2] However, the slit lamp's degree of magnification and changes in depth of field can lead to exaggerated hand movements. The removal technique therefore requires precise hand-eye coordination and extremely fine motor skills, both of which are acquired through extensive practice.[4,5] For this reason, adequate instructions and training for corneal foreign body removal (FBR) is critical in ophthalmic and optometric programs.[3,6,7] Regrettably, there are not enough opportunities for students to gain the necessary practical experience.[3]

Studies have shown that students practicing FBR on simulated eye models improve their confidence levels and skills in that particular art.[3-5] One of the first simulated models, and perhaps the most common, are bovine eyes with embedded metal pieces from an angle grinder.[3] The embedded metal forms rust rings closely resembling those found in the human cornea. This provides a fairly realistic simulation of foreign bodies.[3] The bovine eyes can also be substituted for porcine eyes, depending on the availability from local slaughterhouses.

Deceased animal eyes are relatively cost-effective and readily available. Furthermore, the anatomies of

porcine eyes and bovine eyes are relatively similar to that of human eyes. However, they are biological tissue. As such, disposal of these eyes, and the post-training disinfection process for the tools used, must follow rigorous procedures for biological hazards. The dead tissue will also release unpleasant odors. As a result, an alternative non-animal eye model is preferred.

Several approaches to using non-animal eye models for FBR have been tried. In general, these methods use a readily available polymer, such as paraffin wax, agar or ballistic gel, which is molded into the shape of an eye.[4,5,8] The foreign bodies, consisting of various small pieces, are embedded afterwards. However, these polymers do not mimic the consistency of the cornea, which has a high water content as well as a mechanical strength. Studies have shown that polyvinyl alcohol (PVA) can be used to create an artificial human cornea and vitreous humor.[9,10] PVA is ideal due to its low cost, ready availability, high water content (close to that of the cornea) and excellent mechanical properties.[11-14] It is commonly used in medical devices due to its favorable biocompatibility, chemical resistance and low protein adsorption properties.[14] The advantages of using a PVA eye model for FBR are that students can safely use their own equipment to practice the procedure, there are no rigorous disinfection procedures, and the "eyes" can be kept in storage for long periods of time without spoilage. To our knowledge, eye models using PVA have not been studied. The aim of this study was to create a simple eye model, using PVA, with embedded metal particles that would assist in the teaching of FBR.

Methods

Molds

The molds for the eyeballs were designed using a computer-aided design (CAD) program and were computer numerical control (CNC) machined from acetal plastic. The dimensions for the eye were 22.5 mm x 22.5 mm x 24 mm for height x width x axial length. The molds consisted of two parts, the anterior half for the front half of the eye, and the posterior half for the back of the eye **(Figure 1)**. Additionally, the posterior mold had two holes to allow for filling and the escape of any excess polymer solution. A quarter-inch diameter acrylic rod was used to create a cylindrical hole inside the eyeball to allow for mounting during FBR training.

Figure 1. A: Custom computer numerical control (CNC)-machined molds for the anterior half of the eyeball, the posterior half of the eyeball, and a quarter-inch acrylic rod used to make a hole in the eyeball. **B:** The molds assembled.

Synthesis of polyvinyl eyeball

Dimethyl sulfoxide, and PVA with a molecular weight of (M_w) 89-98 kilodaltons (kDa) (99%+ hydrolyzed), were purchased from Sigma Aldrich (St. Louis, Mo.). The procedure was adopted from methods proposed by Hyon et al.[12] In brief, PVA was added to a mixture of dimethyl sulfoxide and Milli-Q water (8:2) to achieve a concentration of 15% weight/volume (w/v). Milli-Q water, commonly available in most laboratories, is ultrapure water obtained from filtering distilled water through a Millipore ion exchange system. The concentration can be increased if a harder eyeball is desired. The mixture was then lightly stirred for 5 minutes, and then heated in an oven at 115-120^{o}C for 3 hours. After the heating step, the PVA turned clear and viscous, at which point it was poured into the eye mold and the acrylic rod was pushed into the back of the posterior mold to form a cylindrical mounting hole. Subsequently, the mold was held at -30^{o}C for 3 hours for gelation to occur. The gelled eyeballs were then removed from the molds and placed in 500 mL of Milli-Q water, renewed daily, for 3 days to remove the organic solvents.

Foreign bodies

A universal milling machine was used to obtain fine steel particulates from a block of steel metal. The

steel particulates were then filtered using 100 µm x 100 µm, and 300 µm x 300 µm, nylon Spectra Mesh Woven Filters to obtain particle sizes between 100 µm and 300 µm. Several fine particulates of steel were placed in the front half of the eyeball molds and heated at 115-120^{o}C for 15 minutes. The molds were then removed from the oven, and the PVA eyeballs were pressed against the front half of the mold so the front surface of the polymer eyeball re-melted and the heated steel particulates could melt onto the front surface of the eye. The eyeball and the molds were frozen immediately at -30^{o}C for 30 min for re-gelation. The eyeballs were then removed from the molds and stored in Milli-Q water until use. After approximately 24 hours, the steel particulate naturally formed a rust ring in the model eye.

Mount structure

A custom mount to secure the eyeball to a slit lamp headrest was designed using a CAD program. The mount was then cut from quarter-inch acrylic sheets, sourced from the local engineering workshop, using a laser cutter. The structures were assembled and glued together using methylene chloride. A quarter-inch acrylic rod was cut in a 2-mm length to easily mount and dismount the eyeball to the structure.

Students

A total of 50 eye models were used and tested by 90 third-year optometry students during their FBR lab. After the lab, an online survey was sent to all students asking them to rate the usefulness and realism of the simulated eye model for FBR training.

Results

The model eyeball with embedded metal foreign bodies and rust rings are shown in **Figure 2**. The magnified view under the slit lamp clearly shows the foreign bodies and rust rings. The PVA at 15% w/v concentration has a semi jelly-like consistency that is also resistant to puncturing. **Figure 3** shows the custom acrylic structure used to mount the eyeball to a standard slit lamp headrest. Students can easily practice corneal FBR and rust ring removal using the eye model, as shown in **Figure 4**.

Of the 90 third-year optometry students who received the online survey after the FBR lab, 33 responded. More than 72% of the respondents thought the eye models were either very useful (48.48%) or extremely useful (24.24%) in learning FBR, while 70% of the respondents thought the models were fairly realistic **(Figure 5)**.

Figure 2. A: Polyvinyl alcohol eyeball model with embedded foreign bodies and rust ring. **B:** The eyeball model viewed through a slit lamp under magnification.
Click to enlarge

Figure 3. Custom acrylic structure for mounting eyeball to a slit lamp.
Click to enlarge

Figure 4. A: A student practicing corneal foreign body removal. **B:** A student practicing rust ring removal.

Discussion

The present study provides a simple method for creating eye models containing corneal foreign bodies. Multiple iterations of this eye model were vetted, tested and approved by the faculty members in charge of administrating the FBR lab. The final version of the eye model was tested on 90 third-year optometry

students, and based on the survey, the overall response to this model was enthusiastic. More than 72% of the students thought the model was very useful, and 70% of the students thought the model was fairly realistic. The students initially found it challenging to remove the foreign bodies while under magnification from the slit lamp, but after a few attempts they quickly gained confidence in the FBR procedure.



Figure 5. Survey responses from 33 optometry students regarding the realism **(A)** and usefulness **(B)** of the eye model for learning foreign body removal.
Click to enlarge

The most common conventional eye models for teaching foreign body removal are bovine or porcine eyes with embedded metal filings.[3] In the past, we had used porcine eyes, but the disinfection process post-procedure for dead animal eyes was-time consuming and rigorous, and the foul odors were undesirable. We also found that it was difficult to consistently create large enough foreign bodies that were also isolated enough from each other using an angle grinder.[3] Often there would be numerous clusters of extremely fine particles, which could be easily rinsed off with water.

Considering the importance of corneal FBR, very few studies have been published on alternative models to animal eyes.[4,5,8,15] Austin et al. created an eye model using marbles dipped in melted paraffin. The foreign bodies were made from snipping small pieces from an 18-gauge copper wire, and the rust rings were simulated using a rust-colored crayon.[4] Another model, proposed by Cheng et al., used expired agar plates, readily available from the local microbiology departments.[5] Materials such as gravel were used as the simulated foreign bodies.[5] In the past, we have tried both paraffin wax and agar, but found that both materials did not mimic the consistency of corneal tissue. Paraffin wax was too hydrophobic and sticky, while agar was too brittle and soft, and consequently the foreign bodies were removed too easily. An interesting model was proposed by Sayegh et al. It used ballistic gel made from silicone and corn starch.[8] Ballistic gels are a class of gels that mimic the consistency of muscle tissue, and they are typically used to simulate bullet wounds.[16] The foreign bodies were made from paper clips snipped in 2-mm portions using a wire cutter.[8]

We considered two important factors for creating a realistic eye model for FBR. The first was the consistency of the eyeball, which needed to have a high water content and resistance similar to an actual cornea. We chose PVA because of its low cost, high water content[13] and excellent tensile strength.[11] Studies also have shown that it can be used as a material for artificial corneas and human vitreous humor.[9,10] The material synthesis process that we proposed is also flexible. For instance, the concentration of PVA can be increased or decreased to obtain a stronger or weaker gel. Additionally, this approach to synthesizing PVA gels is thermo-reversible, which allows melting of the surface of the gels to incorporate the foreign bodies.

The second important factor we considered was the quality of the foreign body, which needed to be similar to the size of a foreign body typically seen in practice. In addition, the foreign body had to be embedded only on the surface, yet deep enough into the gel to be comparable with what is seen in real-life situations. To ensure similar sizes of our foreign bodies, we obtained filings of various dimensions from a steel block using a universal milling machine and then filtered the filings through 100-µm- and 300-µm nylon filters to obtain particle sizes between 100 µm and 300 µm. We embedded the particles by heating the metal filings to 120^{o}C before pressing/melting them into the eyeball. By freezing the eyeballs rapidly afterwards, the foreign bodies became tightly embedded within the upper layers of the PVA material.

One of the main drawbacks of our eye model for FBR is the lack of Bowman's membrane to resist the penetration of the needle. Without this layer, a student is able to pierce deeper into the eye model than would normally be possible in a real eye. This layer could be simulated by incorporating another thicker layer, made from a higher concentration of PVA or a different polymer such as polydimethylsiloxane. Future studies will examine the synthesis of multiple layers representing different structures of the eye for a more realistic simulation.

Conclusion

This study tested a simple and versatile method for building an eye model to aid in teaching corneal foreign body removal. The eye model is made from polyvinyl alcohol molded into the shape of an eye and embedded with steel particles. The overall eye model has very high wettability and similar consistency to an actual eye, and the foreign bodies also form a natural rust ring. Students can easily use this model with a slit lamp to learn the necessary techniques to remove foreign bodies and rust rings. The advantages of using this model over the traditional bovine or porcine eye is a simpler cleanup, students can use their own equipment to practice, the eyes do not spoil in storage, and there is no unpleasant odor.

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