3D Printed Multimaterial Hydrogels for Color Blindness Correction

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Abstract: - Multimaterial 3D printing is a novel technology with exciting potential. This study explores the use of vat photopolymerization-based 3D printing to build multimaterial hydrogel disks and lenses with increased multiband optical filtering. Such hydrogel devices can be useful for treating ocular diseases including color blindness. The printed multimaterial disks were examined for their optical characteristics and swelling behavior. The optical qualities of the contact lenses were found to be unaffected by the multi-material printing technique. Due to the two dyes that were utilized, the printed multimaterial hydrogels provided a combined multi-band color blindness correction. The obtained optical spectrum closely matched the color blindness correcting glasses that are readily available on the market.

Key-Words: - 3D Printing; Multimaterial Printing; Hydrogels; Color Blindness Correction.

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1 Introduction

Multimaterial 3D printing is a promising technique that has lately attracted a wide range of research interests. Several 3D printing techniques, including fused deposition modeling, material extrusion, and vat photopolymerization, enable multi-material printing. However, for optical applications, the Digital Light Processing (DLP) technique is the most suited process [1]. DLP is a sub-variety of vat photopolymerization that uses an appropriate light projection technology for projecting UV light in 2D patterns on the vat. It has excellent resolution, clean surface quality, and minimal scattering losses. There have only been a few studies on the use of multi-material 3D printing for producing optical applications, including multipurpose contact lenses. Joralmon et al. [2] created liquid crystals whose optical characteristics vary with temperature using multimaterial DLP printing. Bilayer hydrogels that alter color, brightness, and form in response to pH were printed by Li et al. [3]. Multimaterial 1D photonic crystals were manufactured using an e-jet printer by Iezzi et al. [4].

In this study, we investigate the possibility of 3D printing multi-material disks and contact lenses composed of two distinct dyes, each of which may be used to treat specific forms of color blindness. The investigation explores how printing with two different materials affects the optical characteristics of these printed hydrogels. The optical transmission/absorption, swelling, and dye leakage characteristics are studied for this purpose. The produced multimaterial hydrogels are finally compared with commercial glasses available for color vision deficiency.

2 Material and methods

2.1 Resin preparation

For preparing the resin, polyethylene glycol diacrylate (PEGDA) and hydroxyethyl methacrylate (HEMA) were mixed in a ratio of 1:1 by volume and the photoinitiator trimethyl benzoyl diphenylphosphine oxide (TPO) was added at 5% by weight. Two fluorescent dyes, Atto565 and Atto488, were used to color the hydrogel. The dyes were dissolved in the resin using dimethyl sulfoxide (DMSO). Three different dye concentrations were used for the dyes: 1.25%, 2.5%, and 5% by volume.

2.2 CAD modeling and 3D printing

For 3D printing, disk-shaped CAD models were used with dimensions of 14mm in diameter and 1mm/0.5mm in thickness. Contact lens models were also used to print certain samples. Wanhao D8 DLP-based 3D printer was utilized for printing. For printing samples of multiple materials, the print was paused at required points, and the resin in the vat was changed before the print was resumed (Fig. 1).

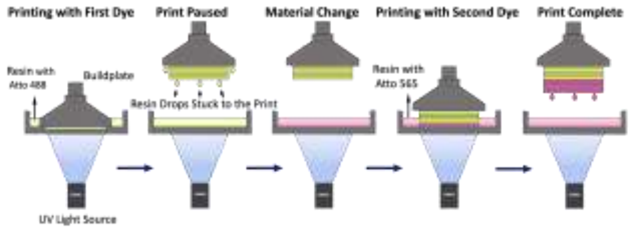

Fig. 1. Multimaterial DLP printing process used in this study.

2.2 Characterization

An Ocean Optics UV-vis spectrophotometer was used to evaluate the transmission/absorption spectra of the liquid resin and 3D-printed samples. To visualize the material change occurring inside the sample, cross-sections of the sample were photographed. By submerging the samples in DI water for lengthy periods, water absorption and dye leakage were examined.

3 Results and discussion

The resins mixed with dyes were found to be quite stable and the dyes did not separate from the resin after the initial mixing. Optical transmission results indicate dips in transmission at 572 nm for Atto565 and 513 nm for Atto488. In addition, a second significant dip appears between 370 and 420 nm because of TPO, which is included in the resin as a photoinitiator and absorbs UV light in this range. Given that both transparent resin and resin with the dye have the same TPO content, they both exhibit the same dip at 370–420 nm. As the dye's concentration rises (from 1.25% to 5%), the transmission dip intensity also rises. The multi-material 3D-printed samples exhibited the same behavior but with two simultaneous dips, one from each Atto565 and Atto488. It was also observed that the transmission was the same whether the two dyes were mixed directly or printed in separate layers as multi-material samples. This similarity in optical transmission demonstrates that the multi-material printing process does not have any negative effects on the optical properties of the printed samples. Even though a small interface was visible on the external surface of multi-material prints, the internal cross-sections did not show an interface, and there was no loss in transmission due to it.

Three combinations, clear resin, clear:Atto565 dyed resins, and clear:Atto565:Atto488 dyed resin combinations were used to print contact lenses. The different dyes were deposited as rings on the curved portion of the lens. These printed samples show that multimaterial contact lenses for optical filtering and other functional purposes can be produced in a wide range of combinations. Comparing the transmission and absorption spectra of multimaterial disks with those of color blindness corrective eyewear that is commercially available reveals a very similar spectral behavior. A considerably closer agreement was obtained than was previously attainable when employing individual dyes [5]. Transmission dips in Enchroma glasses occur at about 486 nm and 575 nm, with corresponding intensities of 0% and 5%. The spectra for Atto565:Atto488 (5%, 2 mm thick), which include transmission dips around 513 nm (7%) and 572 nm (7%), and full-width-at-half-maxima (FWHM) 468-596 nm, are similar to that of Enchroma glasses. BJ-5149 glasses exhibit dips at 513 and 546 nm with intensities of 50% and 55%, respectively, and with an FWHM of 450-570 nm. The spectra for Atto565:Atto488 (2.5%, 1 mm thick) that have dips at 513 nm (57%, FWHM 489-539 nm) and 572 nm (57%, FWHM 550-593 nm) are similar to that obtained for BJ-5149 glasses.

Swelling studies show that all samples have a water absorption capacity of about 10%, with only an approximate 1-2% deviation from this average. These samples took around 24 hours to swell fully from a state of being dry. Samples made of a single substance and those made of multiple materials did not significantly differ in this swelling behavior. Multimaterial printing technique therefore has no impact on the hydrogel's capacity to absorb water. Studies on dye leakage show that there is no evidence of any dye leaking from the two Atto dyes inside the printed sample. The optical spectrum from multimaterial samples revealed that the absorption peak intensity did not change with immersion in DI water.

4 Conclusion

A previously unachieved milestone was reached with the successful 3D printing of multi-material disks and contact lenses incorporating Atto565 and Atto488, which provided optical performance extremely similar to the currently available color blindness correction glasses. The multi-material 3D printing caused no decrease in optical transmission or absorption. Also, even after prolonged immersion in DI water, the color of the multi-material samples stayed the same and they showed no leakage. The study demonstrates that multimaterial printing offers an alternative method to incorporate various colors within a single hydrogel sample.

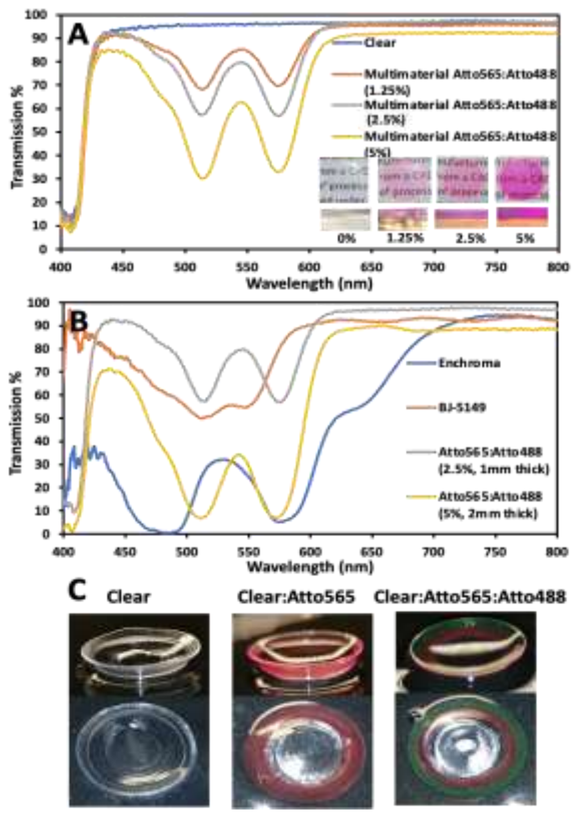

Fig. 2. (a) Transmission spectra from multimaterial disks of different concentrations. (b) Comparison of transmission spectra of commercial glasses and multimaterial disks. (c) 3D printed multimaterial contact.

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Muhammed Hisham carried out the experiments and wrote the paper.
Haider Butt has organized and supervised the project.

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Conflict of Interest
The authors have no conflicts of interest to declare that are relevant to the content of this article.