Prototyping eye dropper tips to reduce drop size through 3D printing

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More people than ever are choosing topical drop solutions as a non-invasive and convenient method of treating eye diseases. Despite its popularity, most commercially available eye droppers deliver a drop volume that exceed the capacity of the eye's precorneal area, resulting in wasted medication and adverse systemic effects. This study aimed to create 3D printed eye dropper tips of various sizes to determine one that could accurately dispense an optimal drop of 15 µL. The 3D printed tips had diameters that were too large to fit into the bottleneck, and the diameter of the inner tube was too small for a hole to be formed. The results of this study suggest that 3D printing is not an effective way to create eye dropper tips and that alternative materials should be explored.

Introduction

Ocular drug administration through aqueous drop solutions remains a popular and convenient method of treating eye diseases, disorders, and discomfort (Patel et al., 2013). In 2018, just under 107 million Americans reported using eye drops and eye washes, a figure that is projected to increase to 110 million users by 2020 (Statista, 2018).

Despite the widespread use of topical eye drops, several studies suggest that there is significant variability in the average drop size of many commercially available eye droppers. In one recent investigation, 192 samples from 32 bottle designs of glaucoma medications were determined to have an estimated drop size range of 24 µL to 221 µL (Moore et al., 2017). Another study tested 145 samples from 20 different manufacturers and found that the drop volume varied from 25.1 µL to 56.4 µL, with an average of 39.0 µL (Lederer et al., 1986).

Proper eye drop administration requires that the drop volume does not exceed the capacity of the conjunctival sac (i.e. the space between the eyelids and the eyeball that is lined by conjunctiva membrane). Given that its maximum capacity is about 30 µL under normal conditions (Gaudana et al., 2010; Mishima, 1981), smaller volume drops of 15 µL to 20 µL should be instilled to minimize systemic side effects through absorption and prevent wasted medication through overflow.

The purpose of this project was to determine the hole size in an eye dropper tip so that it dispenses drops of 15 µL when held vertically at a 90° angle. The approach taken was to replicate a dropper tip in a 3D modelling program, alter the dimensions of the dropper tip, 3D print the design, and measure the volume of the drop delivered from the modified tip.

Materials and Methods

Modelling a Dropper Tip

60 mL indicator eye dropper bottles were purchased from Westlab, and the internal and external dimensions of the included dropper tips (Fig. 1) were measured using digital calipers (Mastercraft Electronic Caliper with Digital Display).

Fig. 1. Dropper tip from a Westlab indicator eye dropper bottle: (A) top view of tip; (B) side view of tip; (C) bottom view of tip.

A basic 3D model of the dropper tip was replicated in TinkerCAD using the original dimensions. The diameters of the base and the inner tube were altered as deemed appropriate throughout the prototyping and printing process.

For the final version of the 3D model, a solid parabolic cone shape was used for the top of the dropper tip, a parabolic cone was used to create a hole out which an aqueous solution would be delivered (top radius: 1.00 mm; bottom radius: 0.50 mm; height: 40.20 mm), two solid cylinders were used for the base of the dropper tip (top: 17.61 × 17.61 × 0.71 mm; bottom: 15.70 × 15.70 × 7.71 mm), and a spherical hole was created to fit inside the base (12.50 × 12.50 × 15.60 mm) (Fig. 2).

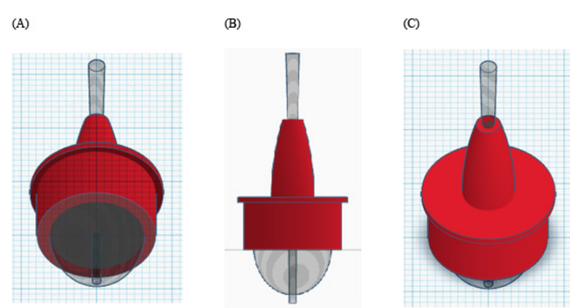

Fig. 2. Final version of the 3D print model for the dropper tip: (A) front-bottom view of model; (B) front view of model; (C) front-top view of model.

Printing the Modified Dropper Tips

The 3D print models were exported as .STL files and sliced on Tinkerine Suite 2. The following slicing settings were used: "high" for the printing resolution, "dense" for the 3D print density, "2" for the shell thickness, and "off" for the overhang support structure feature.

The dropper tip models were 3D printed on a Tinkerine DittoPro 3D Printer using Tinkerine filament.

Preparation of 0.9% Saline Solution

A saline solution was created to imitate the surface tension of a typical solution found in many eye droppers. To achieve a 0.9% concentration, 4.767 g of sodium chloride was measured using a milligram scale (American Weigh Scales GEMINI-20 Portable Milligram Scale) and dissolved in 500.0 mL of distilled water.

Calibration Curve

To determine the unknown drop volume dispensed by the modified dropper tips, a calibration curve (Fig. 3) of mean drop mass against drop volume was constructed. In 5.0-µL increments from 0.0 µL to 50.0 µL, one drop of saline solution was delivered from a micropipette (Rainin Pipet-Lite XLS Micropipette and Rainin RT-250 Pipette Tips) onto a milligram scale on which the mass of the drop was determined. This was repeated for a total of five trials (Table 1).

The mean mass for each drop at every 5.0-µL increment was calculated by adding the measurements and then dividing the value by the total number of trials.

A linear regression line, as can be seen in Fig. 3, was calculated from the data points.

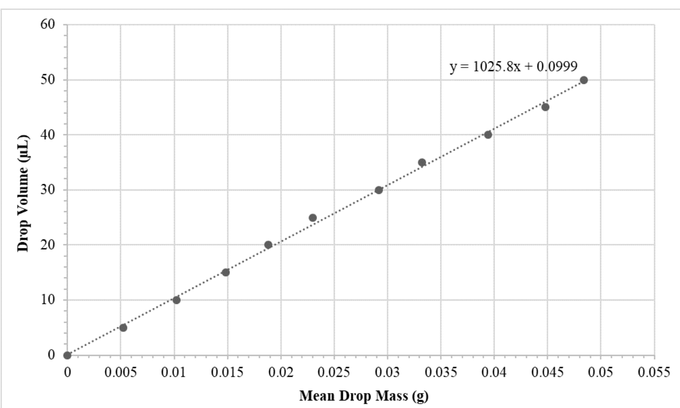

Fig. 3. Calibration curve of mean drop mass against drop volume.

Table 1. Mass of drops with volumes from 0.0 µL to 50.0 µL, measured in 5.0-µL increments.

Drop Volume (µL)	Drop Mass (g)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
0.0	0.000	0.000	0.000	0.000	0.000	0.000
5.0	0.005	0.005	0.006	0.005	0.005	0.005
10.0	0.010	0.012	0.009	0.010	0.010	0.010
15.0	0.012	0.015	0.015	0.015	0.017	0.015
20.0	0.019	0.018	0.019	0.019	0.019	0.019
25.0	0.026	0.021	0.025	0.022	0.021	0.023
30.0	0.032	0.029	0.031	0.025	0.029	0.029
35.0	0.034	0.033	0.033	0.032	0.034	0.033
40.0	0.040	0.037	0.040	0.040	0.040	0.039
45.0	0.046	0.046	0.044	0.046	0.042	0.045
50.0	0.051	0.047	0.048	0.049	0.047	0.048

Determination of an Unknown Drop Volume

A modified dropper tip was fitted into an eye dropper bottle. A drop of saline solution was delivered at a 90° angle onto a milligram scale, and its mass was measured. The unknown drop volume was determined from the y-axis of the calibration curve using the linear regression equation (Fig. 3).

Results

A total of seven eye dropper tip designs were modelled and 3D printed. The base diameter of the final 3D printed dropper tip fit into the bottleneck well enough to stay put when turned over, but not enough to seal the hole, causing leakage during testing. Furthermore, the internal diameters of the tips were too small for the 3D printer to replicate; no hole was printed at the top of the dropper tip when a value below 1.00 mm was used.

Discussion

The results of this project suggest that discrepancies between 3D modelling and 3D printing must be factored in during the prototyping process and altered accordingly for every printer. Most 3D printers can only print to an accuracy of 1 mm. This resolution may not be fine enough to prototype dropper tip sizes.

From the mean mass calculations in Table 1, it was shown that there is a variance in drop volume from the micropipette. A linear regression analysis of dropper volumes indicates that for the drop volume to be 15 µL, the drop mass had to be 0.0145 g. This information can be used in future prototyping studies.

References

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