BIOCOMPATIBLE 3D-PRINTED PEG-DIACRYLATE MICROFLUIDICS

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ABSTRACT

This work describes a new biocompatible open-source material for 3D-printing microfluidic devices using stereolithography. It is a resin consisting of only low-molecular weight poly(ethylene glycol) diacrylate and a photoinitiator. We demonstrate that with the resin it is possible to 3D-print a microfluidic device capable of holding liquid in its channels without absorbing it, and that the material is biocompatible. We expect to integrate this material as the base resin to 3D-printing microfluidic devices due to its properties and low cost.

KEYWORDS: PEG-DA, 3D-printing, Stereolithography

INTRODUCTION

In the past two years, the use of commercial 3D-printing service bureaus to build microfluidic devices in transparent plastic using stereolithography has become an increasingly popular prototyping method [1, 2]. WaterShed XC 11122 stereolithography resin is optically-transparent, water-resistant, and has been certified to pass minimum biocompatibility requirements. However, it is optimized for use in expensive 3D systems stereolithography printers which cure in the UV light spectrum, and some literature reports poor biocompatibility in primary cell culture systems. Here we present a new biocompatible "open-source" stereolithography printing material formulated using only low-molecular weight poly(ethylene glycol) diacrylate (PEG-DA) and a commercial photoinitiator (Irgacure). Two different photoinitiators were used, Bis(2,4,6-trimethylbenzoyl)-phenylphosphineoxide (Irgacure 819 or I819) and Bis(.eta.5-2,4-cylcopentadien-1-yl)-bis(2,6-difluoro-3-(1H-pyrrol-1-yl)-phenyl) titanium (Irgacure 784 or I784), in different concentrations. With this simple resin we expect to be able to print biocompatible, low cost, complex devices with a faster prototyping process.

EXPERIMENTAL

The 3D-printing was performed in a FSL3D Pegasus Touch stereolithography printer (~$3000) which utilizes laser galvanometer steering of a 80 μm-diameter 405 nm laser, with prints built using the constrained-surface technique. Several cubes with four channels connected to a central square well were printed to test the capability to print structures and resolution by using different resin formulations consisting of variable proportions of PEG-DA and two types of photoinitiator, I819 and I784, that have a two important differences, their color and absorbance to UV light. I784 is approximately twice as absorbant as I819 at 405 nm. The resin formulations are listed in table 1. After every print, the parts where left on a UV lamp overnight to finish the curing process.

Table 1. Resin formulation

Component	% by Mass
Formulation 1	
PEG-DA (MW 250)	97.8 – 99.92
Irgacure 819	0.08 – 2.2
Formulation 2	
PEG-DA (MW 250)	99.37 – 99.73
Irgacure 784	0.27 – 0.63

After testing the resolution of different formulations and be able to print channels, a resin consisting of 99.28% PEG-DA and 0.72% I819 was used to print three parts: (1) a simple microfluidic device, where a dye was flowed through the channels and left inside for ~24 hrs. to observe whether there is any penetration of dye into the material; (2) a 35 mm well to test the biocompatibility of the resin through a cell culture assay using RBL-1 cells; and (3) a 32 well custom device to carry out a protein adsorption test using albumin from bovine serum (BSA), tetramethylrhodamine conjugate.

RESULTS AND DISCUSSION

We have tested a variety of formulations using PEG-DA and both photinitiators at different relative concentrations. We printed a simple cube structure that contained a square well and four microchannels connecting the well with the side walls of the cube (Fig. 1a). Sidewall definition is independent of resin formulation (see Fig. 1b and c, top row). However, the ability of any given formulation to define the microchannel roof is highly dependent on photoinitiator concentration: higher photoinitiator concentration resulted in less overcuring (see Fig. 1b and c, bottom row).

These results may be interpreted by analyzing the light absorbance of the resin, and in particular of the photoinitiator. Both photoinitiators have a colored appearance, I819 is a yellowish powder and I784 orange, so when the concentration is higher, the resin has a s higher absorbance due to the resin color (Fig. 1b and c, top row right). If the absorbance is too low, the light will penetrate more than desired and channels will have a reduced height. For example, as shown in Fig. 1, a concentration of 2.2% of I819 or 0.7% I784 is required to achieves a square channel; the absorbance of formulations containing less I819 or less I784 do not let the channel form completely. As photoinitiator concentration increases we gain resolution but the printed part acquires an undesirable tint; in addition, at very high photoinitiator concentrations the photoreaction proceeds very fast and the first layers of the printed parts bend due to thermal stress generated by the heat of the reaction. We conclude that the printing process of these biocompatible polymers is best controlled in optical systems that favor high absorbance (i.e. by adding dyes or by using UV light, in which the resin has a much higher absorbance), so that printing does not need to proceed exothermically.

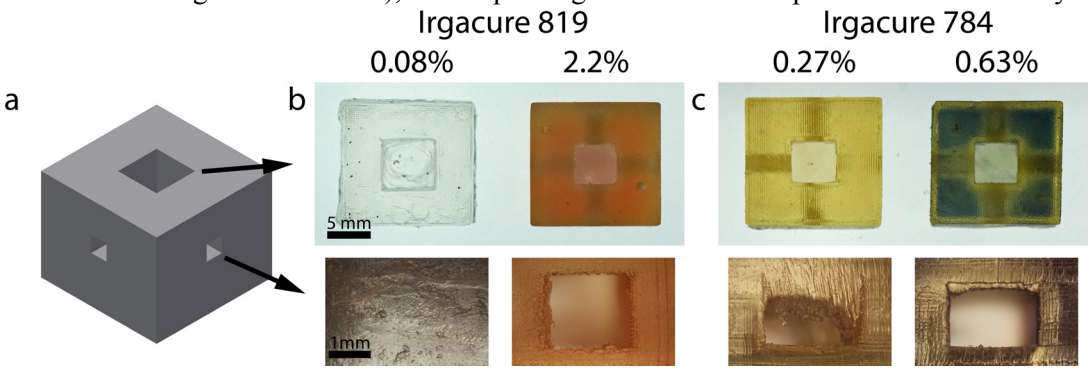

Figure 1: 3D-printed PEG-DA cubes. (a) Design of the cube. Arrows indicate where the pictures were taken. (b) Cubes printed with PEG-DA/I819. Top row shows the surface of the cube with square well and bottom row a photograph of one square channel of the walls. (c) Cubes printed with PEG-DA/I784. Scale bar is the same for each row.

To test the impermeability of the material, a microfluidic device was 3D-printed and the channel was filled with a dye for ~24 hrs. As seen in Fig. 2a, the channels contain the dye and there is no visible penetration of the dye through the walls. For protein adsorption studies, PEG-DA was compared to glass, PDMS and tissue-culture treated polystyrene and results are shown in Fig. 2b where it can be seen that PEG-DA shows to have a similar behavior to PDMS and glass.

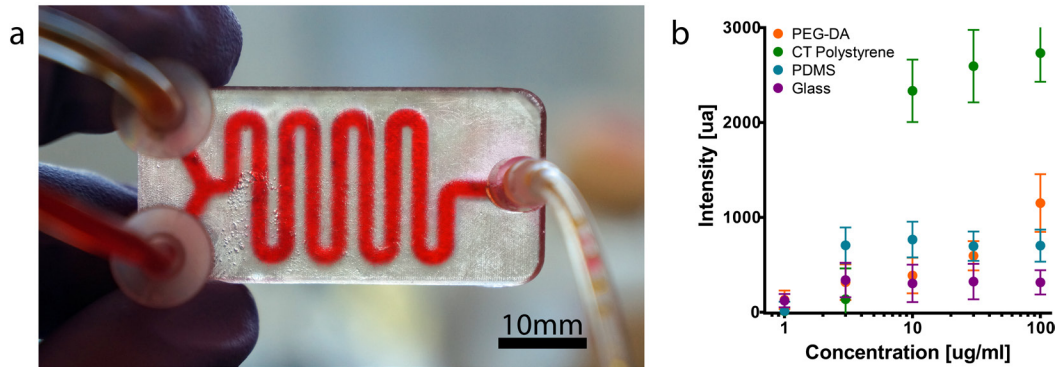

Figure 2: (a) 3D-printed microfluidic device filled with dye. The photograph was taken ~24 hrs. after the device was filled. (b) Chart of protein adsorption tests showing the concentration of BSA-tetramethylrhodamine vs intensity of fluorescence for each material.

To test cell culture compatibility we used RBL-1 cells, a rat basophilic cell line that grows in suspension culture. The cells were cultured (at a density of 750,000 cells/mL) in DMEM supplemented with 10% fetal bovine serum, for 24 hours, in a 35 mm diameter 3D-printed PEG-DA well. The 3D-printed wells were treated with UV overnight. Cell viability was tested by Trypan Blue exclusion assay in the beginning and after 24 hours. We observed a 71.7% increase in the number of live cells in the PEG-DA wells, which was comparable to the 88.9% increase in live cells cultured concurrently in polystyrene dishes. In contrast, the number of live cells in a similar well printed with commercially available resin (FSL3D Clear Resin) decreased by 20%.

CONCLUSION

The results obtained are promising. Even when there are some issues to overcome, different components can be added to the resin to change its properties, as absorbance and color, but it could also be used as it is presented here to fabricate microfluidic devices with complex structures that are not possible to fabricate with techniques as soft lithography. PEG-DA 3D-printed devices are rigid and seem to be not permeable to liquids, which means that all the structures designed for commercial resins should be easily fabricated with it, including valves and pumps [3, 4]. Also, since it shows to be biocompatible, PEG-DA 3D-printed microfluidic devices could be fabricated to do cell studies.

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