Optical Characteristics of 3D printed Novel Light Guide

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1. Introduction

As highly conformal radiation therapy is becoming common, plastic scintillation detectors have been shown to suit the most complex and demanding radiation therapy treatment plans due to water equivalence, energy independence, dose rate linearity and workability [1].

We are conducting a study on free-shaped plastic scintillator, such as tumor and organ-shape, printed using a 3d printer for radiation therapy and development of all related system in order to determine the correct dose rate.

There is a problem that the light intensity and the isotropy of light propagation generated in free-shaped scintillator are not independent on the direction of radiation irradiation due to rugged surface of free-shaped scintillator.

So, a novel light guide for covering a free-shaped scintillator tightly and collecting the constant amount of light regardless of the irradiation direction is needed. So, the dose rate could be constant and reproducible regardless of the direction of irradiation.

In order to fabricate complex-shape light guide mounting and tightly surrounding free-shaped scintillator, 3d printing technology is inevitable. Before printing a novel light guide, it is essential to find proper resin to be used as a light guide and study on that characteristics. Accordingly, these prior studies were conducted in this study.

2. Methods and Results

2.1 Resin components

Because of good transparency, polymethylmethacrylate (PMMA) was desirable as a base ingredient of the resin. However, it was hard to make PMMA light guide using a DLP 3d printer. Even though several different kinds of photoinitiator were used and light intensity was changed, it was not cured. Instead of PMMA, 3 different acrylic monomers were used.

We firstly designed three kinds of resin, which were UV-polymerizable, based on 3 different acrylic monomers, and doped with the same photoinitiator. The recipes for the 3 different resins are as follow.

Resin-1 was composed of 99.9 wt% Trimethylolpropane ethoxylate triacrylate (SIGMA-ALDRICH) as the monomer and 0.01 wt% Lucirin TPO (Aladdin Industrial Corporation) as the photoinitiator. Resin-2 was composed of 99.9 wt % Trimethylolpropane triacrylate (TOKYO CHEMICAL INDUSTRY) as the monomer and 0.01 wt % TPO as the photoinitiator. Resin-3 was composed of 99.9 wt% 1,6-Hexanediol diacrylate (SIGMA-ALDRICH) as the monomer and 0.01 wt% TPO as the photoinitiator. In order to dissolve TPO well in each monomer, these resins were stirred for 15 minutes in water baths at 50℃.

2.2 Fabrication

Resins-1, 2, 3 were polymerized into the simple square shape (each square size: 20×20×10mm) using a DLP 3d printer (Asiga Pico2 HD). The exposure times of these resin-1, 2, 3 that came with the 3d Asiga printer were 1.05 s/layer, 1.4 s/layer, 2.0 s/layer, respectively, at 28℃ when each layer thickness was 0.080 mm. Table I shows the photographs of the polymerized resin samples using Asiga printer and PMMA (ACRYLMALL) of which size was the same as resin samples. It was apparent that Resin-1 is more transparent than Resin-2, Resin-3.

Table I : Pictures of polymerized samples

PMMA	Resin-1	Resin-2	Resin-3
			

2.3 Transmissions and attenuation coefficient

Transmissions of the resin samples printed and PMMA of the same size as samples were measured with Spectrophotometer (CARY 300 CONC) as shown in Fig. 1.

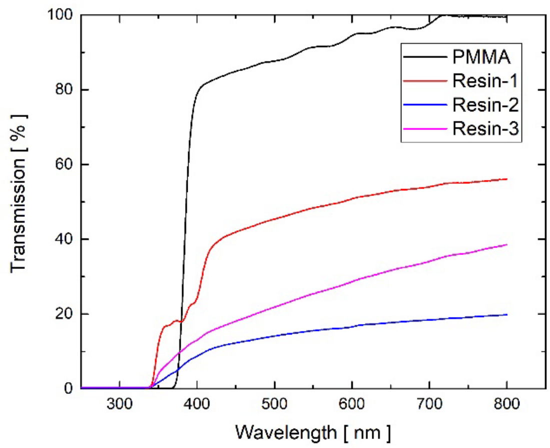

Fig. 1. Transmissions of the polymerized resin samples (Resin-1, 2, 3) using 3d printer and PMMA measured by spectrophotometer for each wavelength.

Using the above Fig.1 data, attenuation coefficients (α) of light were calculated according to formula as below:

$$I = I_0 e^{-\alpha(\lambda)x}$$

where I_0 and I are the intensities of light at a given wavelength λ before and after passing through a resin path of length x. The calculated result of attenuation coefficient for each resin is plotted in Fig.2.

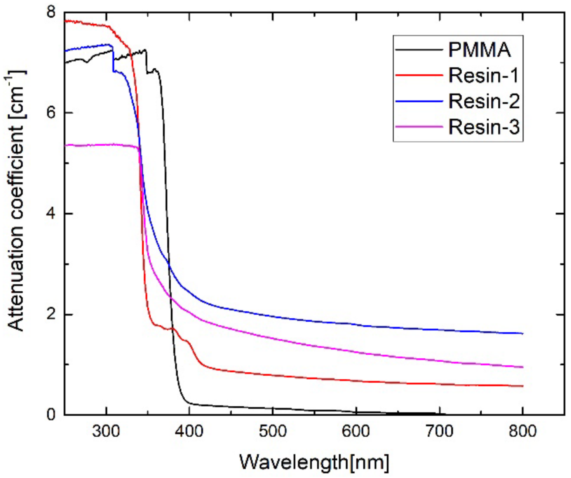

Fig. 2. Attenuation coefficient of polymerized resin samples (Resin-1, 2, 3) using 3d printer and PMMA.

At the blue end of the spectrum, attenuation coefficients of all samples are strong due to Rayleigh scattering [2]. Considering attenuation coefficient, Resin-1 was regarded to be optimal for light guide transporting light. Considering the scintillation emission of a typical plastic scintillator (maximum around 425nm) [3], Resin-1 had lowest attenuation coefficient in that emission wavelength range among printed resin samples.

2.4 The variation of the pulse height with the length of the light guide

In order to observe the positions of the pulse height channel according to various lengths of printed Resin-1 and to check energy transfer characteristics of light in Resin-1 and PMMA, we experimented as shown in Fig. 3.

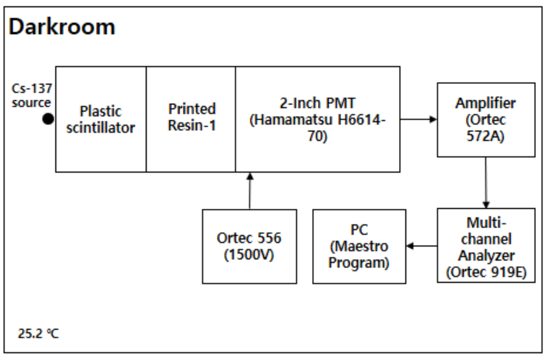

Fig. 3. Schematic of the experimental setup for measurement of transmission.

BC408(Saint gobain, 20x20x10mm) scintillator was connected to PMT (Hamamatsu H6614-70) via Resin-1 prints of various lengths (bottom dimensions: 20x20mm). Light pulses were produced in BC408 scintillator by ^{137}Cs, and confirmed the Compton edge position changed with various lengths of Resin-1 prints and PMMA light guides [4]. The results were plotted with B-spline curves as shown in Fig. 4.

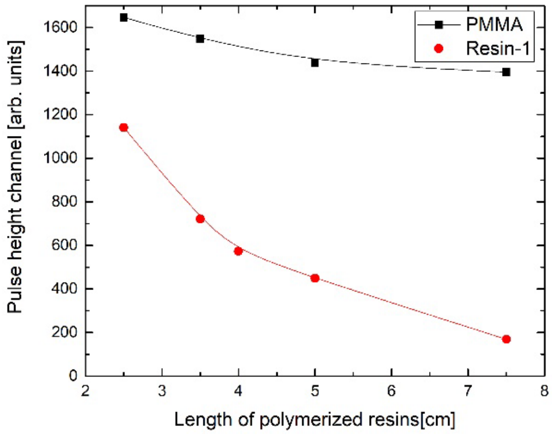

Fig. 4. Performance of a scintillation detector using Resin-1 printed and PMMA of varying lengths (with the same teflon coating as a reflector).

Photons interacting through incoherent scattering lost some energy and continued through material. So, Resin-1 light guide had lower energy transfer characteristics than PMMA.

3. Conclusions

The resin for novel light guide was investigated. The optical characteristics of Resin-1 was not as good as PMMA. However, it is possible to fabricate complex-shape object with Resin-1 using a 3d printer. Consequently, studies on the optimal resin for 3D printing will be carried out to fabricate a light guide for covering tightly a free-shaped scintillator and collecting the constant amount of light regardless of the irradiation direction. Furthermore, independence of the detector response on the irradiation direction will be confirmed using a 3d printed light guide mounted with free-shaped scintillator.

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