Preparation and characterization of tissue phantoms using spatial frequency domain imaging technique for training an artificial neural network

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***Abstract* — We described a method for preparing and characterizing polydimethylsiloxane (PDMS) phantoms for training an artificial neural network that mimics the optical properties of biological tissues. The present method for manufacture solid optical tissue phantoms using a dye absorber chromophore has demonstrated high photostability with optical absorption coefficients up to 0.5 mm^{-1}, making this spectrum suitable with absorption bands ranging from 400 to 1000 nm. The optical scattering properties were quantitatively selected by adding concentrations of TiO_2 particles to the PDMS phantom. Thus, the quantitative optical properties of absorption and scattering for a manufacturing batch of 25 items were demonstrated, making these phantoms suitable for use in optimization algorithms for training a neural network.**

***Keywords* — optical phantoms, machine learning, spatial frequency domain imaging, optical scattering, optical absorption.**

I. INTRODUCTION

The development of a diagnostic imaging system or even some therapeutic interventions requires phantoms that simulate a biological pattern with optical properties similar to tissues[1]. Phantoms are regularly applied to ensure the safety, elaboration, or improvement of treatment techniques, especially in tumors. Their functions are associated with the elaboration of test systems, signal-to-noise ratio optimization in systems, comparison of performance between systems, and realization of a daily routine in clinical devices, guaranteeing greater credibility to the results to reduce the chances of damaging the biological tissues. Solid phantoms are preferred, as they are more stable over time and are easier to measure. Typically, polyurethane or polydimethylsiloxane (PDMS) are used as the primary matrix, mixed with titanium dioxide (TiO_2) or powdered aluminum oxide (Al_2O_3) as the desired scattering coefficient, and a specific chromophore, such as nanoparticles, Nankin ink, or a specific dye matching the desired absorption spectrum[2].

II. METHODOLOGY

The phantoms used to mimic the optical tissue properties in this work consisted of three components: the substrate (PDMS), the absorption agent (India ink), and the scattering agent (TiO2). We prepared 25 different phantoms varying the amounts of India ink and TiO_2. First, the PDMS was measured by weight (approximately 60 g) and added to a container. India ink was measured by volume and also added to the substrate. All components were mixed using a mechanical mixer until they had a homogeneous appearance. After this, the curing agent was added to the suspension, mixed using the mechanical mixer and add to a mold. The final suspension was placed in a vacuum chamber to release bubbles. After removing the bubbles, we leave the containers at rest for 24 hours to cure.

To obtain the phantom or tissue's optical properties, we needed to make measurements of the diffuse reflectance, the diffuse transmittance, and the collimated transmittance. One possibility to determine the optical properties of tissues is using an integrating sphere (IS)[2], as schematically represented in Figure 1. The integrated sphere technique provides a rapid and accurate tool to solve the scattering inverse problem in turbid media[3]. In this technique, measurements of total diffuse reflectance and transmittance of a sample are employed with a mathematical model for optical parameters estimation.

Our lab has used a routine Matlab program based on the general equation for the radiative transfer of stead state in plane-parallel layers. The inverse adding doubling (IAD) method is a general and numerical solution of the radiative transfer equation. This method was developed by S. Prahl for scattering media, especially for biological tissues[3]. The IAD method can be used together with the integrating sphere to find the absorption and scattering coefficients. These properties were obtained by repeating the radiative transfer equation (ETR) solution until the result was close to the experimental data of transmission and reflection[4]. Other

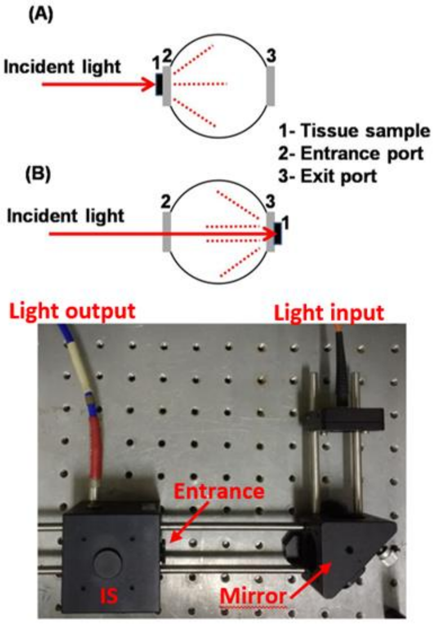

Fig 1. Schematic view of a integrating sphere (IS) for determining the optical properties of tissues. (A) Transmittance mode (B) Reflectance mode.

precise solutions for ETR are too slow or insufficiently flexible to incorporate the boundary conditions required for scattering media, such as the Monte Carlo method.

Besides, spatial frequency domain imaging (SFDI)[5], as a non-invasive method, was used to measure the phantom's optical parameters. SFDI device consisted of a light projector using a halogen lamp to illuminate the sample with spatially modulated sine projections. The diffuse reflectance from the phantoms was captured using a CCD camera working with calibrated filters to select the wavelengths (500, 650, 680, 750, 780, and 810 nm). The same technique was able to analyze tissue depths of about 1 to 5 mm and measure spatially resolved concentrations of clinically relevant chromophores such as oxyhemoglobin, deoxyhemoglobin, lipids, water, and melanin[6]. The obtained phantom's optical properties were intended to program an artificial neural network (ANN) in this work. The employed ANN consisted of a multilayer perceptron, with an input layer, a hidden layer, and the output layer. The input layer consisted of two nodes that received peer values of diffuse reflectance (one value for each spatial frequency). The hidden layer consisted of 50 nodes and the output layer returned the corresponding values of absorption and reduced scattering coefficients. The ANN was trained and tested with values generated by a Monte Carlo database, using backpropagation with the Levenberg-Marquardt algorithm and the mean squared error as a loss function[7].

III. RESULTS

Twenty-five silicone phantoms were produced for use in testing, calibration, standardization, and optimization of equipment and optical techniques used in this work. Furthermore, they were used to train an artificial neural network. The 25 phantoms produced, along with the different amounts of PDSM, TiO_2, and India ink are shown in Figure 1. They were prepared to mimic optical properties of biological tissues in the 400-1000 nm range and were built in two formats: cylindrical, with a diameter of 6.5 cm and height of 2 cm; and rectangular cuboid, with dimensions of 4.5 cm x 4.5 cm x 2 cm.

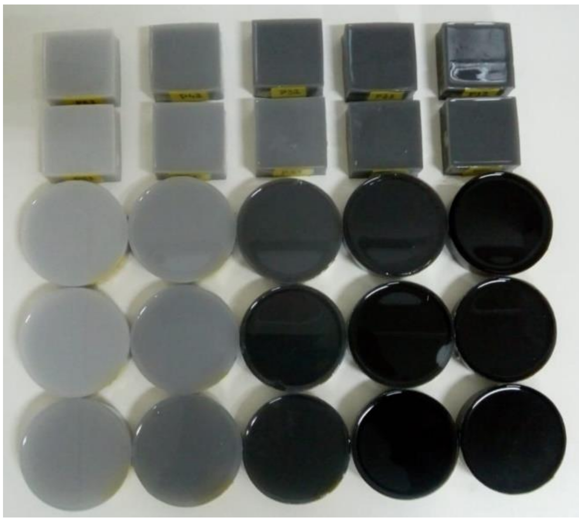

Fig 2. 25 phantoms with different amounts of India ink and TiO2. They were manufactured in cylindrical and rectangular cube formats.

Figure 3 shows the reduced scattering coefficient (μ_s') of some phantoms from the batch. All of them have different concentrations of scattering agents (TiO_2). The concentration varies from the highest to the lowest such as P41 > P42 > P43 > P44 > P45. To keep the same absorbing characteristics, the amount of India ink was kept at approximately 80 µl. Figure 4 shows the absorption spectra of some phantoms with different India Ink concentrations. The concentration varies from the highest to the lowest such as: P15 > P25 > P35 > P45 > P55. To keep the same scattering characteristics, the amount of TiO_2 was kept at approximately 15,0 mg.

IV. DISCUSSION AND CONCLUSION

We presented the methodology for manufacturing and characterizing the phantoms that mimic optical properties of biological tissues in the 400-1000 nm range. These optical phantoms may play a central role in the development, validation, and applications aimed at biomedical technologies. The phantoms based on PDMS fulfilled our requirement since the quantitative optical properties of absorption and scattering were obtained. Furthermore, they demonstrated to be suitable

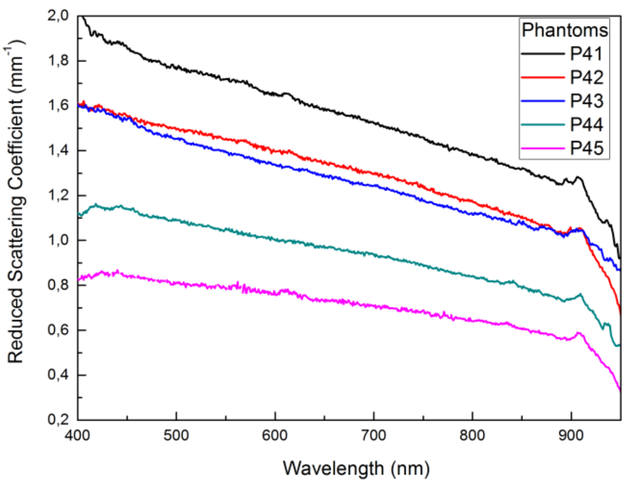

Fig 3. Reduced scattering coefficient (μ_s') versus wavelength for different amounts of scattering agent (TiO2). In order to keep the same absorbing characteristics, the amount of India ink was kept at approximately 80 µl in 60 g of PDMS.

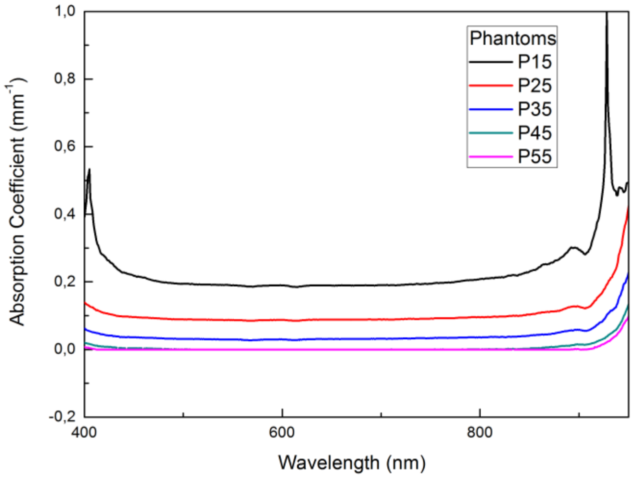

Fig 1. Absorption coefficient (μ_a) versus wavelength for different amounts of absorption agent (India Ink). In order to keep the same scattering characteristics, the amount of TiO2 was kept at approximately 15,0 mg in 60 g of PDMS.

for use as a standard phantom for use in optimization algorithms to train a neural network.

ACKNOWLEDGMENT

This work was supported by the Brazilian agencies CNPq and FAPEMIG.

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