

OPTICAL TISSUE-EQUIVALENT PHANTOMS FOR MEDICAL IMAGING

R. Srinivasan*, D. Kumar and Megha Singh

Biomedical Engineering Division,
Indian Institute of Technology Madras
Chennai – 600 036

Medical imaging with laser radiation, especially for early detection of cancer is gaining importance as this is based on refractive index variation which is quite sensitive parameter in contrast to parameters used in other diagnostic techniques. Optical scattering of various sheep organs were measured by laser reflectometer and their surface reflectance profiles were determined. Tissue equivalent optical phantoms for these tissues were prepared from paraffin wax by mixing a specific combination of wax color materials till the best fit surface profile of the phantoms with that of their corresponding tissues were achieved. The optical parameters absorption coefficient (μ_a), reduced scattering coefficient (μ_s) and anisotropy factor (g) of tissues and phantoms were determined by Monte Carlo simulation technique. Based on this technology tissue equivalent optical phantoms for optical imaging of healthy and diseased organs could be developed and their optical parameters determined.

INTRODUCTION

Clinical diagnostic imaging with laser radiation is not only a novel concept but also an appealing one. In recent times, tissue characterization with laser radiation is widely gaining importance as a diagnostic tool since laser radiation is noninvasive unlike X-rays. Photon transport is based on the spatial variations in refractive indices in a tissue medium. By analyzing the photon-tissue interaction by a suitable technique one can determine the spatial distribution of refractive indices in the medium. Moreover, detection of changes in the refractive indices of a medium is more sensitive parameter than X-ray attenuation coefficient or mismatch of ultrasonic acoustic impedance. At the early stages of cancer development in tissues the refractive index of the tissue is changed leading to the significant change in optical scattering. Therefore, optical imaging is ideally suitable for early detection of tissue abnormalities than the existing imaging modalities [1].

The tissue equivalent phantoms play an important and crucial role in evaluating any new diagnostic or therapeutic

modality. These are also important for calibration and standardization of the new technique before putting it into clinical practice. For this purpose many materials have been used as optical phantoms for optical imaging studies this includes agar gel [2], intralipid [3, 4], India ink [5], milk [6], blood [7] etc., but none of these has the desired qualities of an ideal phantom.

Therefore the objectives of the present work are not only to develop tissue equivalent optical phantoms of freshly excised sheep organs by analyzing the spatially resolved steady state diffuse surface reflectance measurements but also to determine their optical parameters through Monte Carlo Simulation technique.

MATERIALS AND METHODS

Laser reflectometer

The laser reflectometer detects the backscattered photons from various layers of tissue/phantom. The photons emerging from the deeper layers are measured at farther distance from the beam entry point and vice versa [8]. By measuring these backscattered intensities the tissue/phantom's surface emission profile was determined. The schematic of laser reflectometer used for measuring the surface profile is shown in figure 1. This

* *Bajpai-Saha Award for best presentation - First Prize.*
Correspondence to Dr. Megha Singh
email : msingh@acer.iitm.ernet.in

system consists of laser source (670nm, 2mW), optic fibre-probe assembly consisting of one source fiber and three collecting fibers, photo-detectors, current-voltage converter and an ADC interface with a PC. The details of the system are described elsewhere [9].

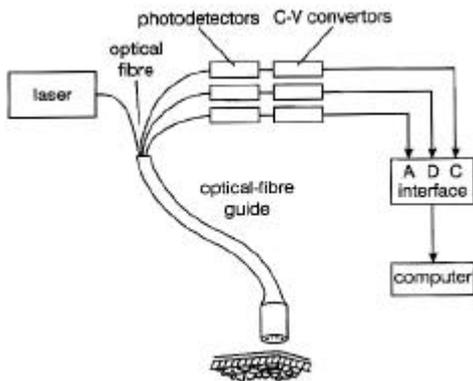


Fig.1: Schematic of laser reflectometer

Tissue preparation

Freshly excised sheep organs such as bone, cerebellum, heart, kidney, muscle and spleen were procured from a commercial butcher and cleaned thoroughly to remove dirt and blood. They were soaked in physiological saline for about 30 minutes to remove any excess blood. Prior to measuring their reflectance the organ surface was mopped with blotting paper to remove saline and moisture.

Monte Carlo Simulation

Monte Carlo simulation is a stochastic technique; it has been widely applied in radiation transport studies since photon tissue interaction is a random process. The scheme of the simulation is shown in the figure. 2 [10]. Further details of the application of this procedure are given elsewhere [11]

Data Collection and Analysis

The surface reflectance of sheep organs were measured by holding the probe

head of laser reflectometer perpendicular to the tissue surface. The measured values were expressed as percentage of normalized data with respect to the maximum reflectance value when the source fibre was held directly at the photo detector. These normalized backscattered intensity (NBI) values were plotted against the radial distance from the source entry point.

Phantom preparation

To 100 ml of melted white paraffin wax, measured quantities of wax coloring materials (Ganesh coloring company, Chennai, India) were added and stirred gently to achieve uniform distribution of color pigments in the medium. Thereafter this was poured into a glass cylinder of diameter 3.0cm and 10cm length and allowed to cool at the room temperature. After solidification, this was removed from the cast cylinder and their surface reflectance measured.

To facilitate the matching of experimental normalized back scattered intensity profiles with that of phantoms, a color palette was made with different color concentrations of both pure colors as well as different color combinations. A given experimental profile is compared with the nearest profile of the palette. Based on this the phantom was prepared. By similar procedure all other phantoms were prepared.

Monte Carlo simulation scheme as explained earlier was implemented to obtain the diffusely reflected light for a range of reduced scattering coefficient (μ_s), absorption coefficient (μ_a) and anisotropy factors (g). The experimental profile of tissue/phantom was compared with these simulated profiles and the best matching curve was selected by a chi-square test. The parameters μ_s , μ_a and g of the best fit simulated curve was assigned as optical parameters of the corresponding tissue/phantom.

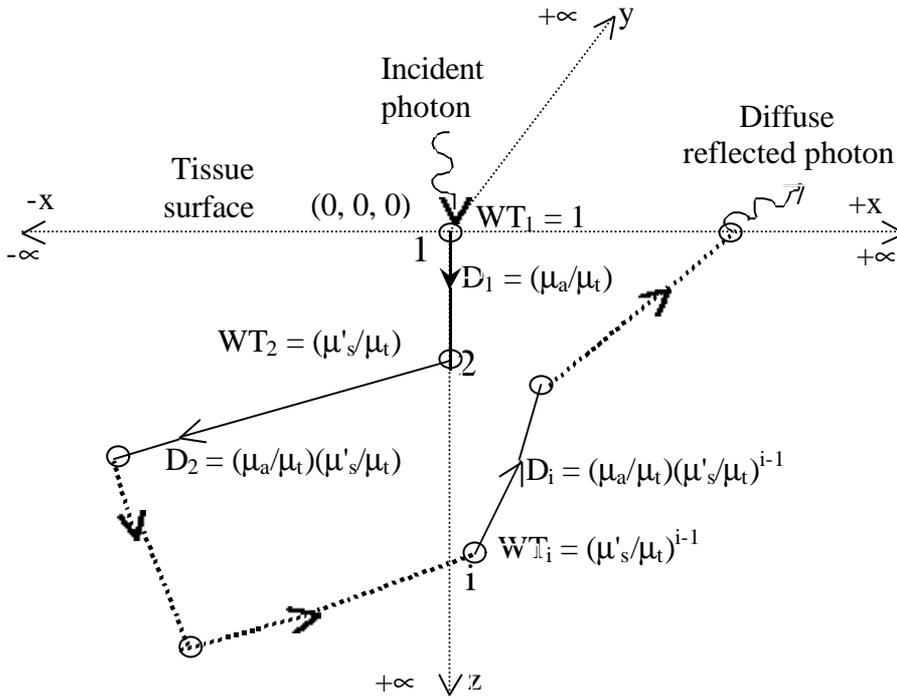


Fig. 2. Scheme of Monte Carlo simulation technique WT = Weight at the i^{th} scattering; D = Absorbed dose at the i^{th} scattering

RESULTS

Experimentally measured normalized backscattered intensity (NBI) profile of sheep's cerebellum and its equivalent phantom is plotted against the radial distance from the beam entry point is shown in Fig.3. A good agreement between these curves indicates that the phantom is optically equivalent to that of the cerebellar tissue. A comparison of the NBI profiles of experimental and tissue equivalent phantoms with that of the best fit Monte Carlo simulation curve is shown in Fig 4. The best fit between experimental and simulated curves shows the equivalence of their optical parameters. By the same procedure matching was done for all other organs as well. Table. 1 shows the determined values of reduced scattering coefficient (μ_s), absorption coefficient (μ_a) and the anisotropy factor (g) of various tissues. μ_s

, μ_a is maximum for muscle and spleen respectively. The anisotropy factor g shows comparatively less variation among different tissues. The color combination details of various tissue equivalent optical phantoms are given in table 2. For muscle phantom red, black and white wax colors were used. For cerebellum and heart only red color of varying concentrations was used. Similarly, for bone and spleen varying concentrations of brown color alone was used.

Discussion

The backscattered intensity profiles has high correlation to the structural and functional details of tissues. It is determined by factors like color, spatial and temporal variations in the tissue structure (cell geometry, cell population, cellular orientation and distribution), blood flow and contents

Table 1. Determined optical parameters for the sheep organs

Tissue	μ_s (cm ⁻¹)	μ_a (cm ⁻¹)	<i>g</i>
Bone	13.8	0.08	0.8
Cerebellum	14.6	0.02	0.74
Heart	13.8	0.18	0.78
Kidney	11	0.01	0.85
Muscle	21.2	0.02	0.74
Spleen	13	2.8	0.78

Table 2. Wax color combination of tissue equivalent phantoms

Tissue equivalent optical phantoms (100 ml of paraffin wax)	Wax color concentration (mg %)			
	Red	Black	Brown	White
Bone	-	0.1464	-	2.342
Cerebellum	2.428	-	-	-
Heart	0.1464	-	-	-
Kidney	-	-	0.0285	-
Muscle	0.142	0.0731	-	2.342
Spleen	-	-	0.5857	-

(amount of blood flow, presence of metabolites, pigments and their functional status) along the tissue.

The reflectance profile is maximum for skeletal muscle and minimum for spleen. Since skeletal muscle is a highly stratified, well organized, light in color and relatively less

vascular tissue, it has the maximum reflectance. On the other hand, spleen owing to its dark colored surface and large amounts of entrapped blood inside it has the least reflectance profile. Even though heart is a muscle, due to the presence of blood inside its cavities it has less reflectance. Cortical bone is highly compact, dense and avascular tissue hence it offers less absorption and more scattering. Kidney is light colored and covered by a glistening avascular capsule which reflects away light and offers least absorption.

These observations are further strengthened by the determined optical parameters for these organs. Tissues and phantoms were characterized by combining experimental measurements and simulation studies. The determined optical parameters show similar trends with other investigators observations [12, 13]. Muscle and spleen has the highest scattering and absorption coefficients respectively. Kidney has the minimum absorption and scattering coefficients.

Tissue equivalent phantoms were made by mixing a specific combination of wax color materials with the paraffin wax. Four color pigments namely red, black, brown and white were used. Of these colors, red and black were highly scattering and absorbing in nature, brown is moderately absorbing while white is a good diluant and moderate scatterer. The reflectance profile along the length of the phantom is uniform ensuring good homogeneity.

In conclusion, the above mentioned techniques could be extended for optical characterization of human organs and development of their equivalent phantoms for medical imaging.

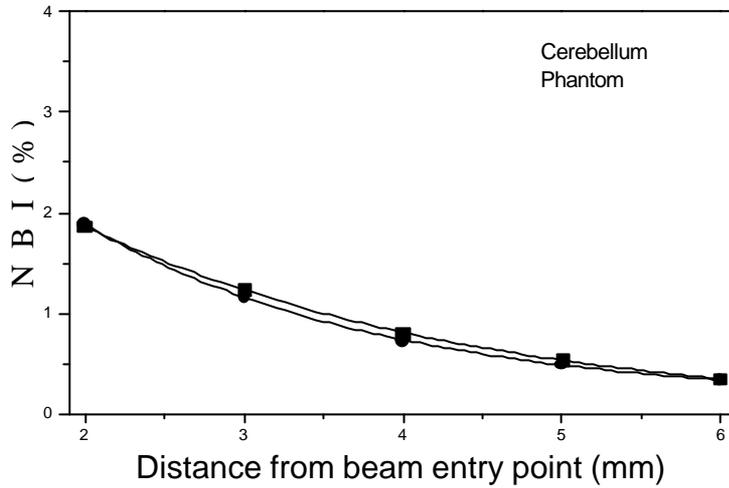


Fig. 3. Comparison of the Normalized backscattered intensity profiles of sheep's cerebellum and its equivalent phantom

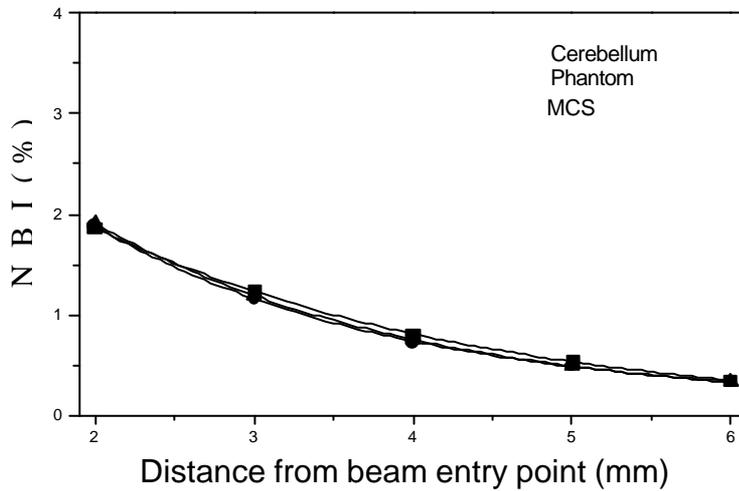


Fig. 4. Normalized backscattered intensity variation of cerebellum and its phantom along with best-fit curve as obtained by Monte Carlo simulation.

REFERENCES

1. Colak S.B., Van der Mark G.W., Hooft W.T., Hoogenraad J.H., Van der Linden E.S. and Kuipers F.A., *Clinical optical tomography and NIR spectroscopy for breast cancer detection*, IEEE J. Selected Topics in Quant Electron, 5, 1143-1158 (1999)
2. Cubeddu R., Pifferi A., Taroni P., Torricelli A., and Valentini G, *A solid tissue phantom for photon migration studies*, Phys. Med. Biol, 42, 1971-1979 (1997)
3. Van Staveren H.J., Moses C. J. M., Van Marle J., Prah S. A. and Van Gemert M. J. C., *Light scattering in intralipid 10% in the wavelength range of 400-1100nm*, Appl. Opt, 30, 4507-4514 (1991)
4. Patterson M.S., Chance B. and Wilson B. C., *Time resolved reflectance and transmittance for the non-invasive measurement of tissue optical properties*, Appl. Opt, 28, 2331- 2336 (1989)
5. Madsen S.J., Patterson M. S. and Wilson B. C. *The use of india ink as an optical absorber in tissue-simulating phantoms*, Phys.Med.Biol, 37, 985-993 (1992)
6. Mitic G., Kober J., Otto J., Piles E., Solkner G. and Zinth W., *Time gated transillumination of biological tissues and tissue like phantoms*, Appl Opt, 33, 6699-6709 (1994)
7. Chance B., Haselgrove J., Wang N.G., Maris M. and Sevick E., *Photon dynamics in tissue imaging*, Proc. SPIE, 1024, 481-491(1991)
8. Nossal R., Kiefer J., Weiss G. H., Bonner R., Taitelbaum H., and Halvin S. *Photon migration in layered media*, Appl. Opt, 27, 3382-3391(1988)
9. Chacko S. and Singh M., *Multi layer imaging of human organs by measurement of laser back scattering radiation*, Med Biol Eng Comput, 37, 278-284 (1999)
10. Wilson B.C. and Adam G., *A Monte Carlo model for the absorption and flux distributions of light in tissues*, Med. Phys, 10, 824-830 (1983)
11. Kumar D., Chacko S. and Singh M., *Monte Carlo simulation of photon scattering in biological tissue models*, Indian J Biochem Biophys, 36, 330-336 (1999)
12. Cheong W., Prah S.A. and Welch A.J., *A review of the optical properties of biological tissues*, IEEE J Quantum Electron, 26, 2166-2185 (1990)
13. Firbank M., Hiraoka M., Essenpreis M. and Delpy D.T., *Measurement of the optical properties of the skull in the wavelength range 650-950 nm*, Phys. Med. Biol, 38, 503-510 (1993)