# Progress in Optical Tissue-Simulating Phantoms


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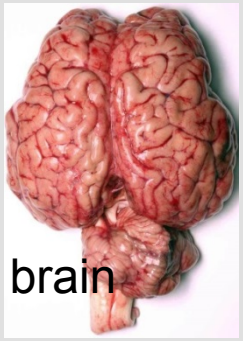
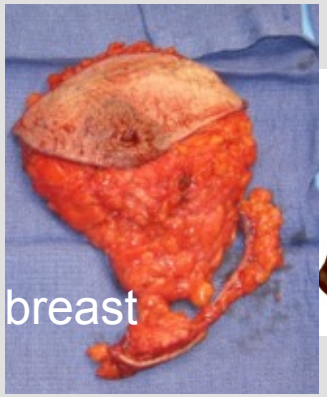
Department of Surgery, Geisel School of Medicine

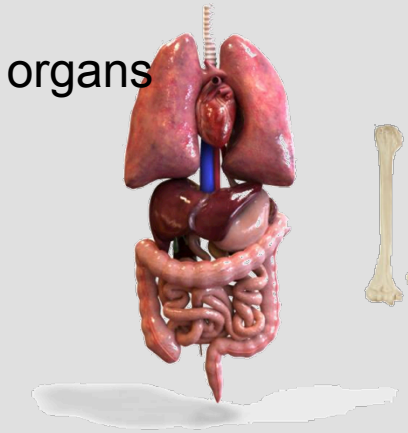

# Macroscopic optical properties come from microscopic & sub-microscopic physiology variation

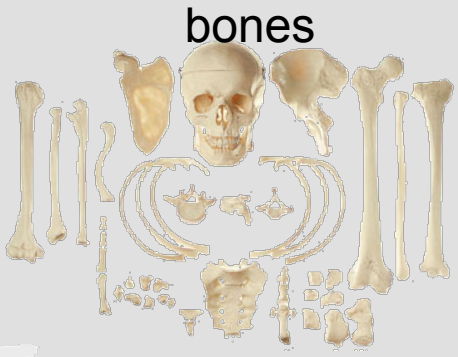
## macroscopic



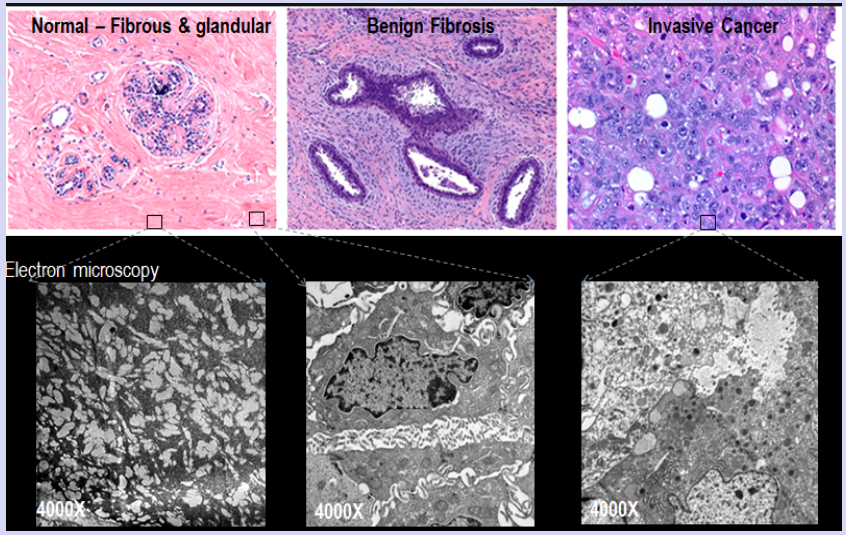








## microscopic




## Sub-microscopic

$$\lambda \cong d_{structure}$$

# Macroscopic catalogues of optical properties have only existed for ~25 years

 **1990** IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 26, NO. 12, DECEMBER 1990

## A Review of the Optical Properties of Biological Tissues

WAI-FUNG CHEONG, SCOTT A. PRAHL, AND ASHLEY J. WELCH, SENIOR MEMBER, IEEE

*Abstract*—A comprehensive compilation of published optical properties (absorption, scattering, total attenuation, effective attenuation, and/or anisotropy coefficients) of various biological tissues at a variety of wavelengths is presented. The theoretical foundations for most experimental approaches are outlined. Relations between Kubelka–Munk parameters and transport coefficients are listed. The optical properties of aorta, liver, and muscle at 633 nm are discussed in detail.

### I. Introduction

THE propagation of laser light in tissue is a question of growing concern in many medical applications. Numerous models that predict fluence rates in tissue, or reflection and transmission of light by tissue have been developed. The accuracy of these models ultimately depends upon how well the optical properties of the tissue are known. Optical parameters are obtained by converting measurements of observable quantities (e.g., reflection) into parameters which characterize light propagation in tissue. The conversion process is based on a particular theory of light transport in tissue.

In past years, a host of investigators have reported values for the total attenuation coefficient, the effective attenuation coefficient, the effective penetration depth, the absorption and scattering coefficients, and the scattering anisotropy factor for a variety of tissues at a variety of light wavelengths. The majority of these results are based upon approximations to the radiative transport theory (e.g., diffusion theory). Yet sufficient variations in 1) model assumptions (e.g., isotropic–anisotropic scattering

A brief description of the radiative transport equation which is basic to all the light propagation models, and its associated parameters appears in Section II. Various solutions are presented to show how optical properties can be determined from using different measurements. Section III compares the Kubelka–Munk coefficients and the transport coefficients. Section IV provides specific descriptions of several methods used to determine optical properties. Section V discusses the measured optical properties for three selected tissue groups at 633 nm.

### II. Light Propagation Models

Most of the recent advances in describing the transfer of laser energy in tissue are based upon transport theory. This theory is preferred in tissue optics instead of analytic approaches using Maxwell equations because of inhomogeneity of biological tissue. According to transport theory, the radiance $L(r, s)$ ($W \cdot m^{-2} \cdot sr^{-1}$) of light at position $r$ traveling in a direction of the unit vector $s$ is decreased by absorption and scattering but it is increased by light that is scattered from $s'$ directions into the direction $s$. The radiative transport equation which describes this light interaction is [1]

$$s \cdot \nabla L(r, s) = -(\mu_a + \mu_s)L(r, s) + \mu_s \int_{4\pi} p(s, s')L(r, s')\, d\omega' \quad (1)$$

**Cited 1,152 times!!!**

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## Oregon Medical Laser Center

**Featuring**

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- NewsEtc. biomedical optics and lasers
- Intro. to Biomedical Optics
- Photodynamic therapy

**A collaboration of**

- The Oregon Medical Laser Center at Providence St. Vincent Medical Center
- The biomedical optics program at Oregon Health and Sciences University

**Biomedical Optics Program, Oregon Health & Science University (OHSU)**

**Biophotonics Resource Center at OHSU**

# First established tissue phantom: Intralipid


**1991**

1 November 1991 / Vol. 30, No. 31 / APPLIED OPTICS 4507

## Light scattering in Intralipid-10% in the wavelength range of 400–1100 nm

Hugo J. van Staveren, Christian J. M. Moes, Jan van Marle, and Martin J. C. van Gemert

The absorption, scattering, and anisotropy c measured at 457.9, 514.5, 632.8, and 1064 nm. in Intralipid-10% were determined by tran performed by using the particle size distrib coefficients from 400 to 1100 nm. The agreeme

**Cited 557 times!!!**

**I. Introduction**

Intralipid-10% is a fat emulsion that is used clinically as an intravenously administered nutrient. Sometimes, as in the research described in this paper, it is used for providing the scattering component in a tissue phantom to investigate propagation of light in tissue. The optical parameters of Intralipid-10%, namely, the absorption coefficient $\mu_a$, the scattering coefficient $\mu_s$, and the anisotropy coefficient $g$ (the

Valu collima apertu 10% su coeffici fluence an infi added- then ca the tra (diffusi

ve previously wavelength.[1,2]


Lasers Surg Med. 1992;12(5):510-9.

**1992**

## Optical properties of Intralipid: a phantom medium for light propagation studies.

Flock ST, Jacques SL, Wilson BC, Star WM, van Gemert MJ.

Phillips Classic Biomedical Laser Research Laboratory, Department of Otolaryngology-Head and Neck Surgery, University of Arkansas for Medical Sciences, Little Rock 72205.

**Abstract**

Intralipid is an intravenous nutrient consis
Intralipid is turbid and has no strong abso
is readily available and relatively inexpens
dosimetry experiments. In order to assist i
wavelengths is optically equivalent to tissu
interaction coefficients of Intralipid, most o
the measurements of the absorption and
attenuation coefficient from 500 to 890 nm
absorption coefficient varies from 0.015 to
varies from 92 to 50 cm-1 between 460 ar
between 500 and 890 nm, and the averag
With these data, we discuss the design of
India ink.

**Cited 258 times!!!**

#92339 - $15.00 USD Received 1 Feb 2008; revised 18 Mar 2008; accepted 4 Apr 2008; published 11 Apr 2008

14 April 2008 / Vol. 16, No. 8 / OPTICS EXPRESS 5907

## Optical properties of fat emulsions

René Michels, Florian Foschum, and Alwin Kienle

*Institut für Lasertechnologien in der Medizin und Meßtechnik, Helmholtzstr. 12, D-89081 Ulm, Germany*

rene.michels@ilm.uni-ulm.de

**Abstract:** We present measurements of the optical properties of six different fat emulsions from three different brands, Clinoleic, Lipovenoes and Intralipid, with fat concentrations from 10 % to 30 %. The scattering coefficient, the reduced scattering coefficient, and the phase function of each sample are measured for wavelengths between 350 nm and 900 nm. A method for the calculation of the particle size distribution of these fat emulsions is introduced. With the particle size distribution the optical properties of the fat emulsions are obtained with Mie theory. Simple equations for the calculation of the absorption coefficient, the scattering coefficient, the reduced scattering coefficient, the $g$ factor, and the phase function of all measured samples are presented.



**OCIS codes:** (290.3030 index measurements; 290.7050 turbid media)

**6 types**

Intralipid® (Fresenius Kabi AB, Uppsala Sweden)
Nutralipid® (Pharmicia, Quebec),
Liposyn® I, II, III (Abbot Labs, Montreal)

Baxter

# Urgent Product Recall

March 11, 2008

RE: INTRALIPID IV Fat Emulsions

**2008**

Dear Director of Pharmacy:

Due to reports of leaking, Baxter Healthcare, the sole distributor of INTRALIPID IV Fat Emulsions is issuing a voluntary recall for its manufacturer, Fresenius Kabi, for the following INTRALIPID IV Fat Emulsion product codes, identified with the following lot numbers:


**Hospira Issues Nationwide Voluntary Recall of Certain Lots of Liposyn™ and Propofol Products That May Contain Particulate Matter**

Nov. 6, 2009 - Lake Forest, Ill. - Hospira, Inc. (NYSE: HSP),, is voluntarily recalling 85 lots of Liposyn™ II 10%, Liposyn II 20%, Liposyn III 10%, Liposyn III 20%, Liposyn III 30% and 73 lots of Propofol Injectable Emulsion 1% … because some of the containers may contain particulate matter. The source of the particulate matter has been identified as stainless steel equipment used in the manufacturing process.

**$50/L (c1990) → $1000/L (c2010)**

# c1993-1995 → Solid permanent phantoms

Phys. Med. Biol. 38 (1993) 847–853. Printed in the UK

NOTE

## A design for a stable and reproducible p
## near infra-red imaging and spectroscop

M Firbank and D T Delpy

Department of Medical Physics and Bioengineering,
Shropshire House, 11–20 Capper Street, London WC

David Delpy

Received 23 November 1992, in final form 10 Febru

**Abstract.** This note describes a stable, reproduci
properties of tissue, for use in near infra-red spectros
The base material is a clear, unpolymerized liquid
of a catalyst. The polyester has a low intrinsic abso
non-scattering. Before the resin is set, measured qu
and absorbing dyes can be added. The scattering-p
measured, and the mean cosine of the scattering angl
the concentration of scattering particles a range of
coefficients can be produced. By varying the conce
coefficient of the resin can be easily controlled.

Phys. Med. Biol. 40 (1995) 955–961. Printed in the UK

## An improved design for a stable and reproducible phantom material for use in near-infrared spectroscopy and imaging

Michael Firbank†, Motoki Oda‡ and David T Delpy†

† Department of Medical Physics and Bioengineering, University College London, First floor, Shropshire House, 11–20 Capper Street, London WC1E 6JA, UK

‡ Central Research Laboratory, Hamamatsu Photonics KK, 5000 Hirakuchi, Hamakita 434, Japan

Received 26 January 1995

**Abstract.** In this note, we describe an improved phantom material for use in near-infrared spectroscopy and imaging. The material consists of a clear epoxy resin with absorbing dyes and amorphous silica spheres as scattering particles. It is possible to calculate the scattering coefficient and angular scattering distribution of the material from Mie theory, using the known size and refractive index of the silica spheres together with the measured refractive index of the resin (~ 1.56). We show a good agreement between prediction and experimental measurements. The scattering properties of the material closely match those of tissue in the near-infrared wavelength region, having an anisotropy factor, $g$, of approximately 0.93.

The absorption coefficient of the epoxy is low (~ 0.001 $mm^{-1}$), and addition of the dyes produces an absorption coefficient that covers the same range as that of tissue.

# UCL BORL Webpage

**Components**

**Epoxy resin**: Araldite epoxy (MY753) & hardener (XD716),
Supplier: Aeropia Chemical Supplies (Crawley, UK).

**Near-infrared dye**: Pro jet 900NP.
Supplier: Avecia (Manchester, UK), formally Zeneca Ltd.

**Scatterer**: "Superwhite" polyester pigment.
Supplier: Alec Tiranti Ltd. (London, UK).

Jem Hebden

# Heterogeneous & dynamic blood oxygenation spectroscopy validation

Phys. Med. Biol. 40 (1995) 2079–2092. Printed in the UK

1995

## A dynamic phantom brain model for near-infrared spectroscopy

C Dean Kurth†, Hanli Liu‡, William S Thayer§ and Britton Chance‡

† Department of Anesthesiology and Critical Care Medicine, Children's Hospital of Philadelphia, 34th Street and Civic Center Boulevard, Philadelphia, PA 19104, USA
‡ Department of Biophysics, University of Pennsylvania School of Medicine, Hamilton Walk, Philadelphia, PA 19104, USA
§ NIM Incorporated, Philadelphia, PA, USA

Received 10 April 1995, in final form 5 September 1995

**Abstract.** This report describes the construction, fluid dynamics and optical properties of an *in vitro* model of the neonatal brain for testing near-infrared spectroscopy (NIRS) instruments. The brain model is a solid plastic structure containing a vascular network perfused with blood equilibrated with $O_2$, $N_2$ and $CO_2$ in a closed circuit. The oxygenation state and haemoglobin concentration of the perfusate can be regulated and measured with a co-oximeter, providing a means to compare NIRS measurements of oxy-, deoxy- and total haemoglobin concentrations and haemoglobin $O_2$ directly with a validated standard method. Fluid dynamic experiments revealed that the model's vasculature remains stable over time with minimal haemolysis. The model's optical properties were characterized by time-resolved and continuous wave NIRS between 670 and 850 nm as perfusate saturation was varied in the range 0–100%. Optical properties of

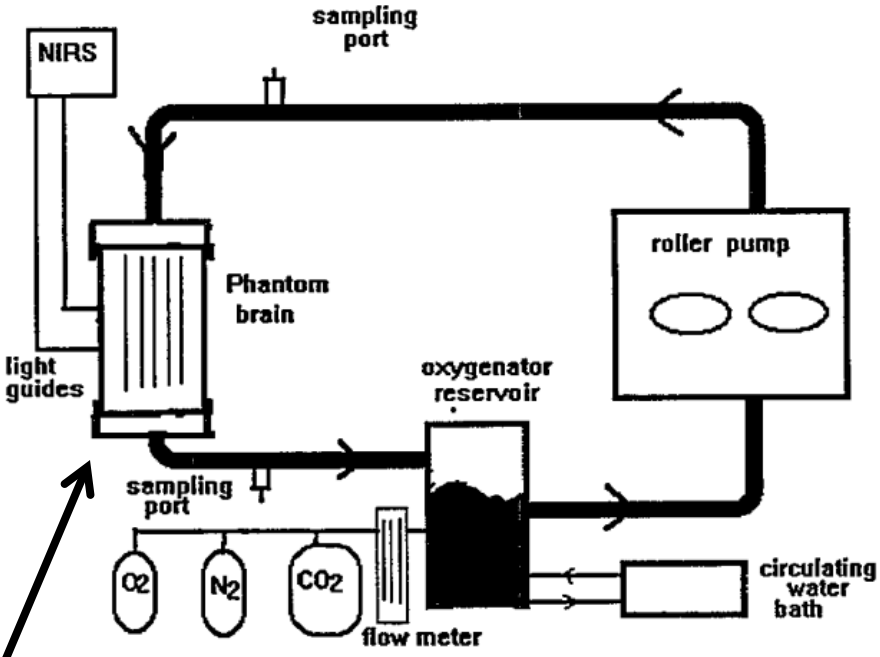
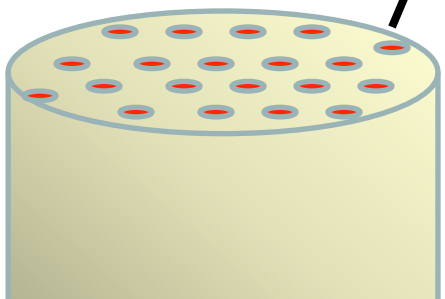
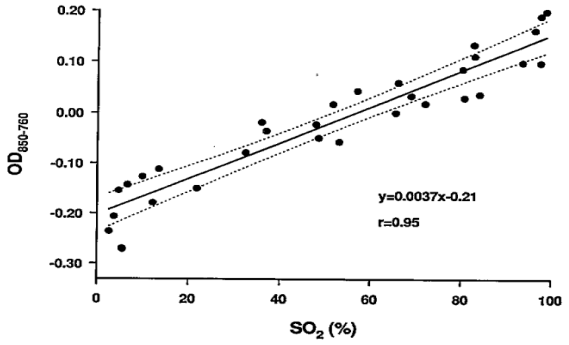


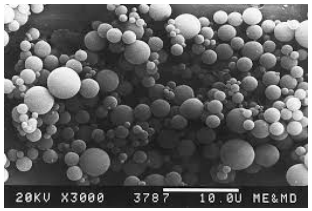

**Figure 1.** A schematic diagram of the dynamic phantom brain model. Arrows denote the direction of blood flow.



# 1) Choose Phantom Scatter

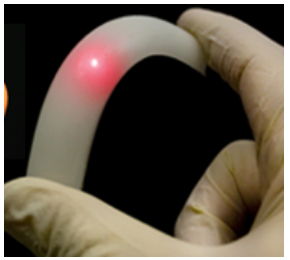
| Scattering Material | Perm-anent ? | Particle Size [nm] | Index of refraction | Particle distribution function | Recommended Use |
|---|---|---|---|---|---|
| **Lipids** | **N** | **10-500 nm** | **1.45** | Exponentially weighted to smaller sizes, impossible to get a single size distribution | - Intralipid , milk, mixture<br>- Theory/Experimental tests & multiple phantom contrast studies |
| **Polymer microspheres** | **Y** | **50nm-100 μm** | **1.59** | Single size function as ordered, with possible 1-2% variance. | -Most accurate theoretical prediction of properties<br>- Use with all aqueous, resin & RTV phantoms |
| **$TiO_2$ $Al_2O_3$ Powders** | **Y** | **20-70 nm** | **2.4-2.9** | Exponentially weighted or single size can be ordered | - Used with gelatin, RTV & resin phantoms |
| **Quartz glass microspheres** | **Y** | **250 nm** | **1.45** | Single size function, with 10% variance | - used with resin phantoms |




**Pogue & Patterson, J. Biomed Opt. 2006**

# 2) Choose Phantom Matrix

| Phantom Matrix Material | Perm-anent | Solid/ Liquid/ Flexible | Biologic Compatible | Organic Chemical Compatible | n | Recommended Use |
|---|---|---|---|---|---|---|
| **Aqueous suspension** | Y/N | L | Y | Y | 1.34 | Initial use & multiple phantom contrast studies |
| **Gelatin/Agar matrix** | N | F | Y | Y | 1.35 | Detailed heterogeneity phantom studies bio-absorbers & fluorophores |
| **Polyacryl. gel** | N | F | Y | Y | 1.35 | Thermal therapy studies |
| **Polyester or Epoxy Resin** | Y | S | N | N | 1.54 | Calibration & routine validation Intersystem comparisons |
| **Polyurethane Resin** | Y | S | N | N/Y | 1.50 | Calibration & routine validation Intersystem comparisons Inclusion of dyes |
| **RTV Silicone** | Y | F | N | N | 1.4 | Complex geometries with permanent flexible phantoms |



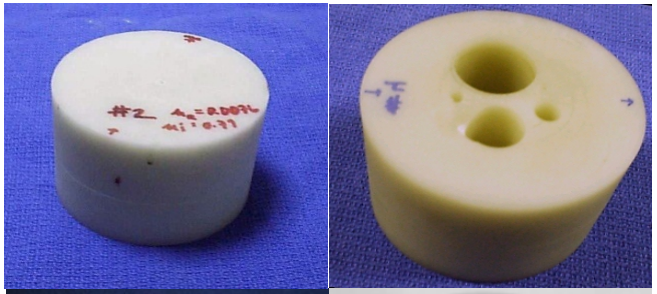
**Pogue & Patterson, J. Biomed Opt. 2006**

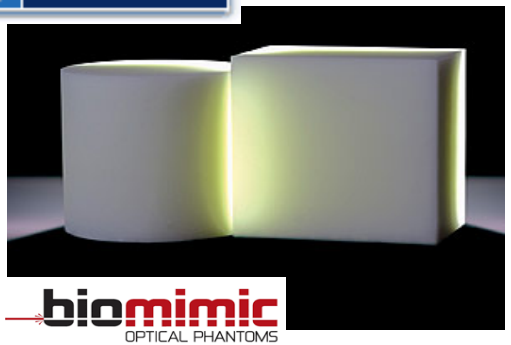
# Widespread use of resin phantoms

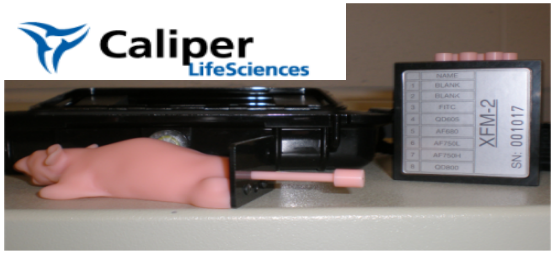
UCL



Dartmouth



1997

# Silicone Rubber base:

## provides better contact & mechanical tissue simulation

Lasers in Surgery and Medicine 21:227–234 (1997)

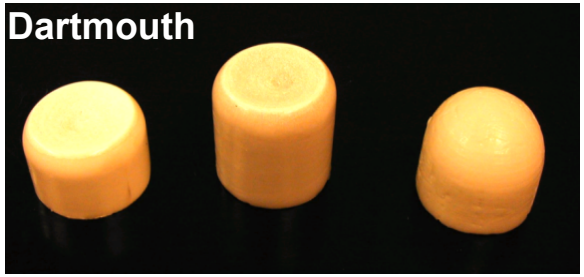
### Three-Dimensional Optical Phantom and Its Application in Photodynamic Therapy

Roland Bays, PhD,[1]* Georges Wagnières, PhD,[1] Dimitri Robert, BS,[1] Jean-François Theumann, PhD,[1] Alex Vitkin, PhD,[3] Jean-François Savary, MD,[2] Philippe Monnier, MD,[2] and Hubert van den Bergh, PhD[1]

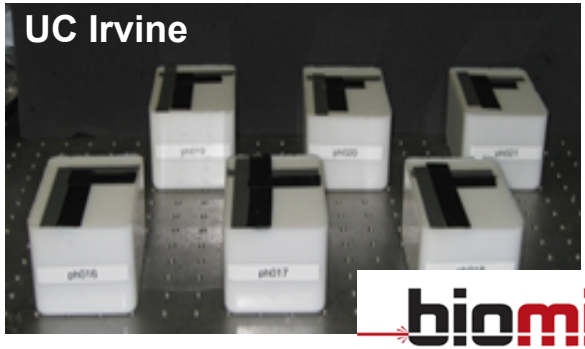
[1]Institute of Environmental Engineering, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland
[2]ENT Department, CHUV Hospital, CH-1011 Lausanne, Switzerland
[3]Medical Physics, Ontario Cancer Institute, Toronto, Ontario M5G 2M9, Canada

***Background and Objective:*** A technique to manufacture a stable, reproducible three-dimensional optical phantom is presented. This phantom reproduces the tissue's optical properties as well as the geometry and, to some extent, the mechanical properties of the organ concerned. Easy to make and to handle, this phantom is a useful tool for numerous medical applications involving light interaction with biological tissues.
***Study Design/Materials and Methods:*** The phantom is based on a transparent two-component silicone, which is molded into the desired shape and cured at room temperature. Specific optical properties are obtained by adding scatterers ($Al_2O_3$ particles or polystyrene microspheres) and absorbers (dyes or pigments). A method to measure the radiant energy fluence rate in the phantom is described. This method is based on a small isotropic optical detector.
***Results:*** A three-dimensional phantom of the bronchial tree is presented. This phantom is used for testing new light distributors designed for photodynamic therapy of the bronchi.
***Conclusion:*** The proposed technique allows one to produce a stable three-dimensional phantom with accurately predictable optical properties. Lasers Surg. Med. 21:227–234, 1997.


**Dartmouth**

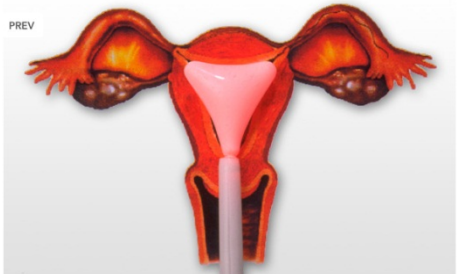


**UC Irvine**

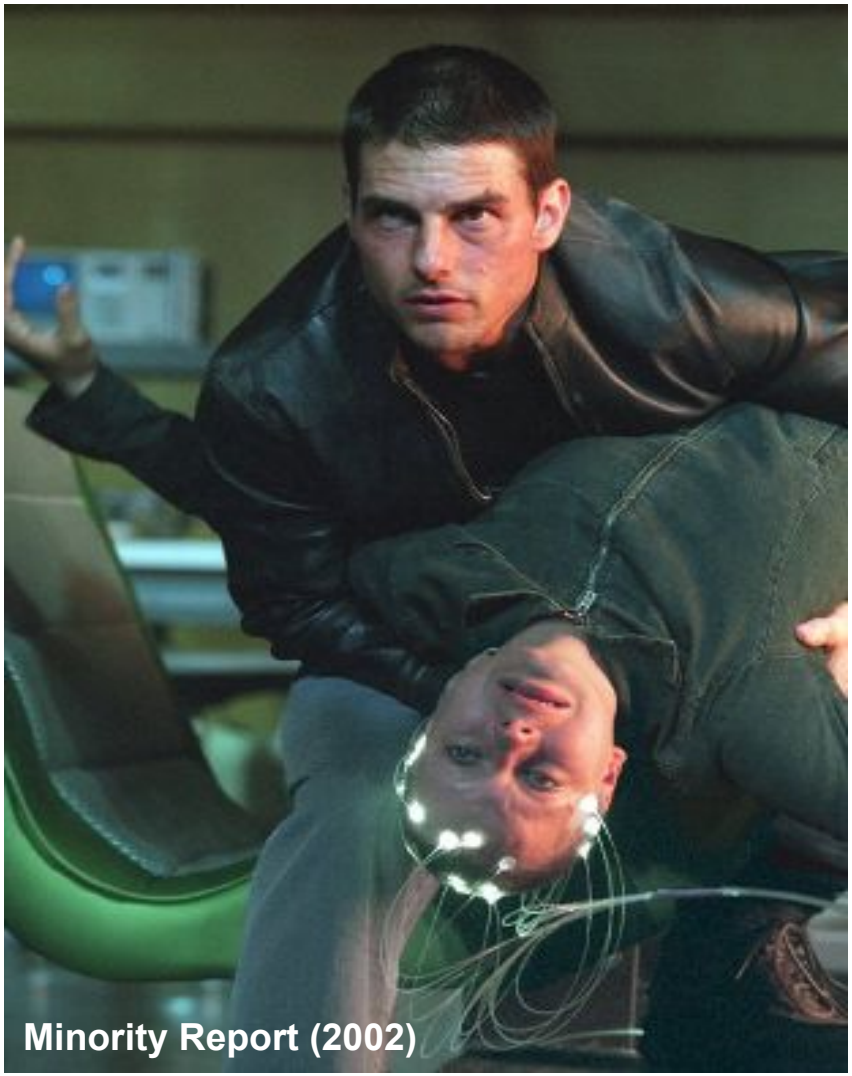


biomimic
OPTICAL PHANTOMS

**Medlight SA, PDT delivery**



# Biological phantoms?



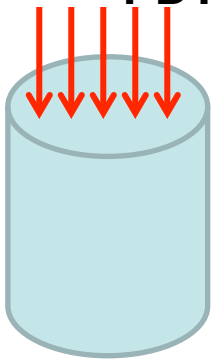
# Gelatin/Agar Base

**Gelatin / agar**

**with TiO2 scatter**

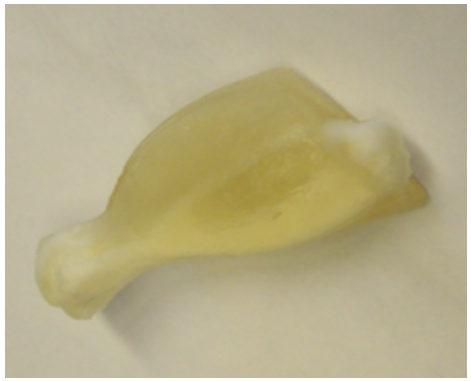
**with blood**

**Chemical actinometry**
**PDT Dosimetry**



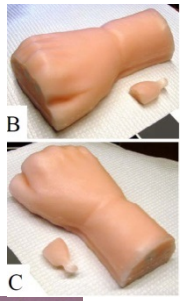
Gelatin
TiO2
ink
dichloroflorescien

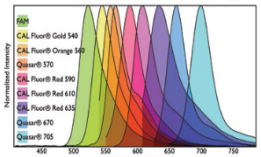
**Bone embedded**

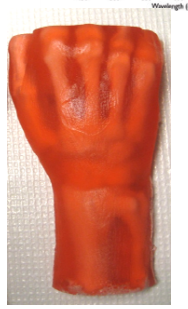


# Phantom additives

| Additives | Function | Limitations | Stability |
|---|---|---|---|
| **EDTA Penicillin** | To avoid bacterial growth | | Days - Weeks |
| **Yeast or Sodium azide** | Remove molecular oxygen | | Hours |
| **Formaldehyde** | Increase melting temperature above room temp. | | Years |
| **Whole Blood** | Provide realistic tissue spectra | Oxygen saturation is not easily changed | Days |
| **Ink** | Provide flat absorption spectra | - Not stable nor repeatable unless highly calibrated | Days – Years |
| **Organic molecules (i.e. glucose)** | Matrix holds most organic compounds | - stability of each molecule must be assessed | Days |
| **Fluorophores** | -Compatible with aqueous<br>- Gelatin provides some de-aggregation | - May need to avoid aggregation effects with addition of additional agents | Days – Weeks |
| **Heterogeneities** | - Test Tomography and Imaging capabilities<br>- Inclusions can be liquid or solid | - Clear enclosures need to be avoided due to light channeling<br>- Index changes significantly at inclusions | Days – Weeks |
| **Gadolinium or Copper Sulphate** | Provide varying levels of Magnetic resonance contrast | | Years |
| **Actinometry agents** | Provide measure of photochemical dose de | Unstable over long periods of time | Hours |







Pogue & Patterson, J. Biomed Opt. 2006

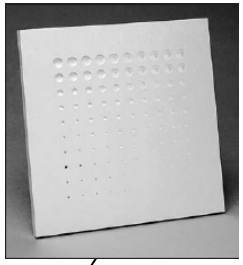
Why?

# Conventional x-ray CT Phantoms

Spatial Uniformity & Dose

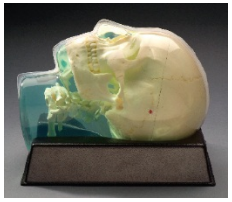
Spatial Resolution

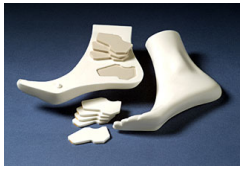
Contrast Resolution



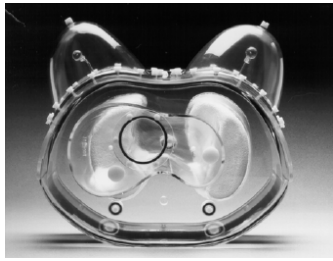
Contrast Calibration

Anthropomorphic Phantoms

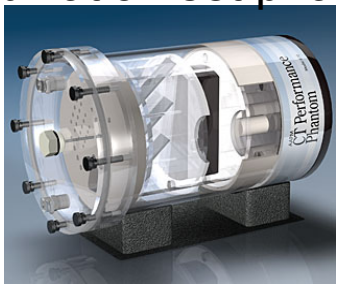




Specialty / Temporal Phantoms



Combination set phantoms




Dozens of manufacturers & Hundreds of suppliers!
Government mandated requirements.
Organizations produce guidelines in conjunction with the respective government agencies

http://www.spect.com
http://www.cirsinc.com
http://www.supertechx-ray.com
http://www.phantomlab.com/

# Key issues medical phantoms

| PURPOSE OF PHANTOM → | Calibration | Performance Assessment (Quality Audit) | Realistic/Specialized Tissue Properties or Geometry |
|---|---|---|---|
| Regulated → | Government / ANSI / AAPM | Voluntary | Optional / Only as needed |
| Completed by who → | Manufacturer & User | User | User / Researcher |
| Specifics of each phantom used → | Uniformity across the field | Contrast Calibration | Anthropomorphic geometry |
| | Linearity of response | Spatial Resolution | Anthropomorphic interior structure |
| | Signal to Noise & repeatability | Contrast Resolution | Biochemical composition |
| | Radiation Dose (CT) RF Dose (MR) | Annual Dose Q.A. (CT) | Viscoelastic / Thixotropic / Rheopectic |
| | | | Temporally varying properties |

Pogue et al, "**Review of Phantoms for Tomographic imaging, with Applications towards Diffuse Spectroscopy within Clinical Imaging Systems**" Proc SPIE (2008)

# Standardization between EU systems

2104 APPLIED OPTICS / Vol. 44, No. 11 / 10 April 2005

## Performance assessment of photon migration instruments: the MEDPHOT protocol

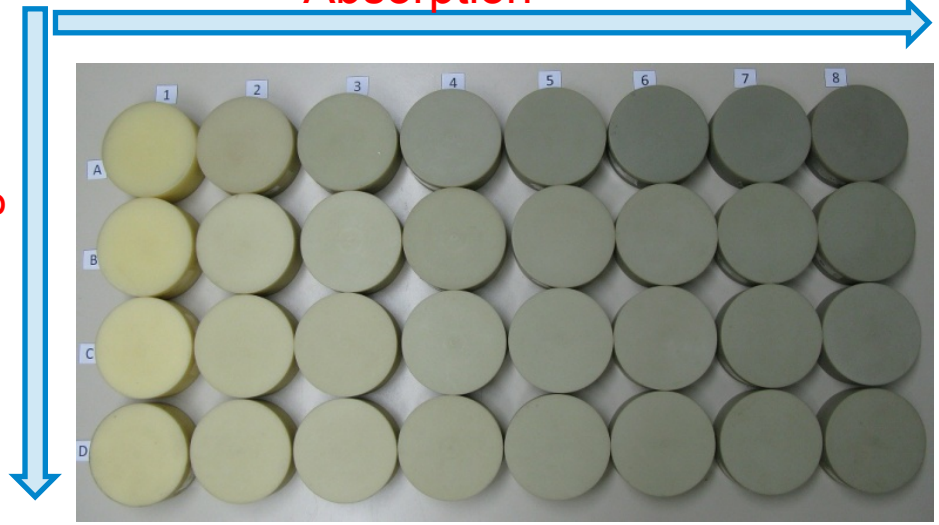
Antonio Pifferi, Alessandro Torricelli, Andrea Bassi, Paola Taroni, Rinaldo Cubeddu,
Heidrun Wabnitz, Dirk Grosenick, Michael Möller, Rainer Macdonald,
Johannes Swartling, Tomas Svensson, Stefan Andersson-Engels,
Robert L. P. van Veen, Henricus J. C. M. Sterenborg, Jean-Michel Tualle,
Ha Lien Nghiem, Sigrid Avrillier, Maurice Whelan, and Hermann Stamm

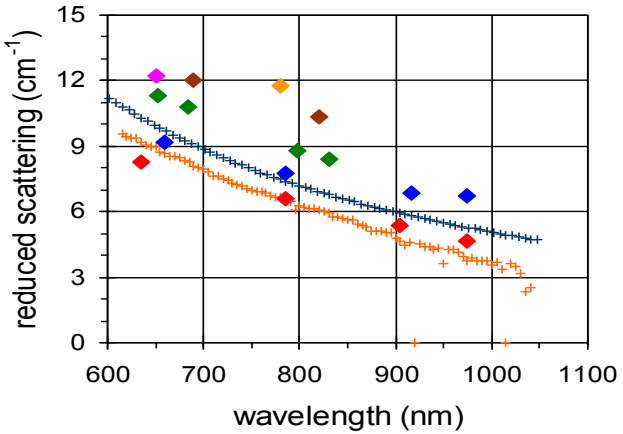
We propose a comprehensive protocol for the performance assessment of photon migration instruments. The protocol has been developed within the European Thematic Network MEDPHOT (optical methods for medical diagnosis and monitoring of diseases) and is based on five criteria: accuracy, linearity, noise, stability, and reproducibility. This protocol was applied to a total of 8 instruments with a set of 32 phantoms, covering a wide range of optical properties. © 2005 Optical Society of America

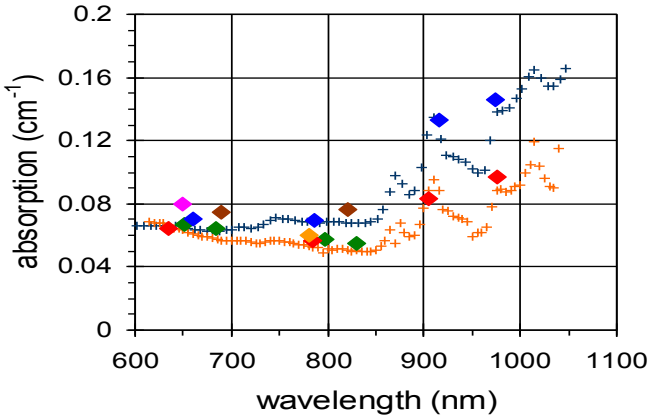
*OCIS codes:* 170.5280, 170.7050, 220.4840, 350.4800, 000.3110.

### 1. Introduction

In the past decade, the field of photon migration has grown rapidly, attracting the interest of researchers in a number of applications in the biomedical field, spanning from optical mammography to muscle and brain oximetry, from tissue spectroscopy to the study of bone and joint diseases, and from optical characterization of photosensitizers to molecular imaging.[1–3] In addition to *in vivo* applications, in which interest has been strong, other fields have been pioneered, such as non-destructive characterization of agricultural products[4] or quality assessment of pharmaceutical tablets.[5] All these applications have fostered the development of a wide collection of instruments based on the detection of light propagated through turbid media. Different tech-



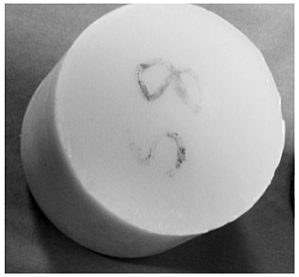




Rigorous science BUT likely not commercial?

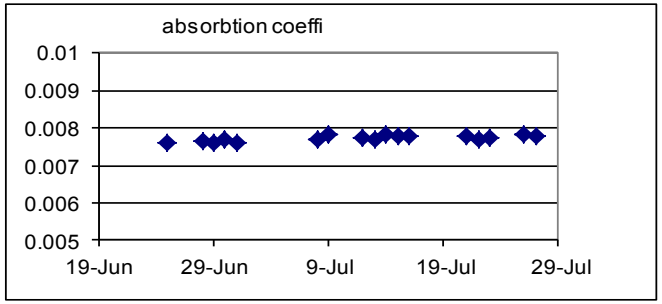
# Key Issues in Phantoms for Imaging & Spectroscopy Systems

| | | |
|---|---|---|
| 1) | Repeatability<br>Standardization | **Critically Needed** especially for commercial systems |
| 2) | Spatial Uniformity<br>Spatial Resolution<br>Contrast Recovery | **Needed for validation** |
| 3) | Viscoelastic effects<br>Athropomorphic artifacts<br>Imaging systems compatibility | **Very Useful in each situation** |

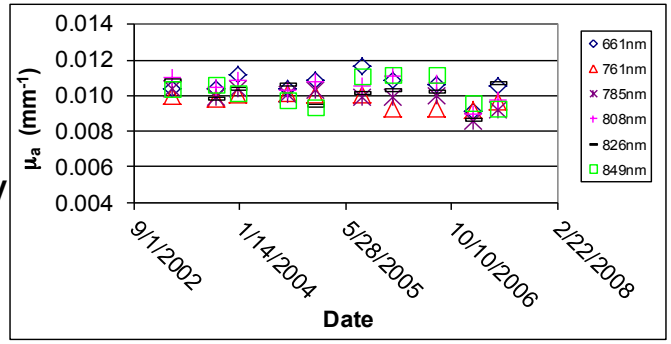
# Daily calibration & intersystem verification



1 month stability




5 year stability





Multicenter trial

# Key Issues in Phantoms for Imaging & Spectroscopy Systems

Repeatability
Standardization

**Critically Needed**

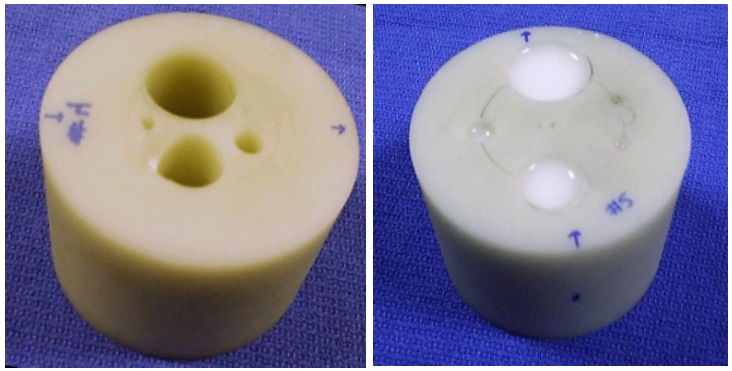
Spatial Uniformity
Spatial Resolution
Contrast Recovery

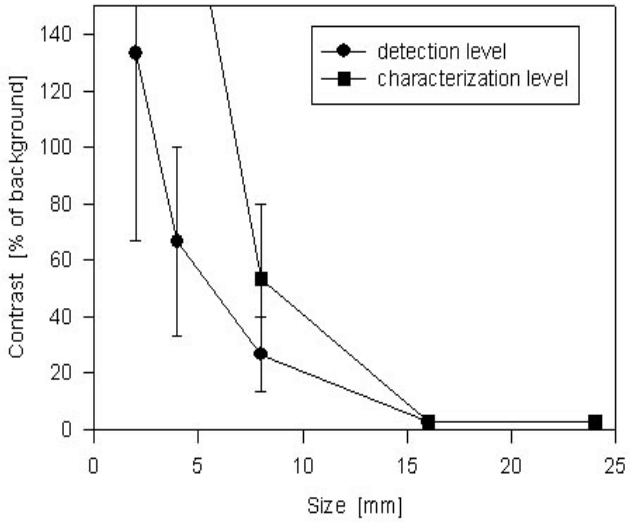
**Needed for validation**
(science or comparisons)

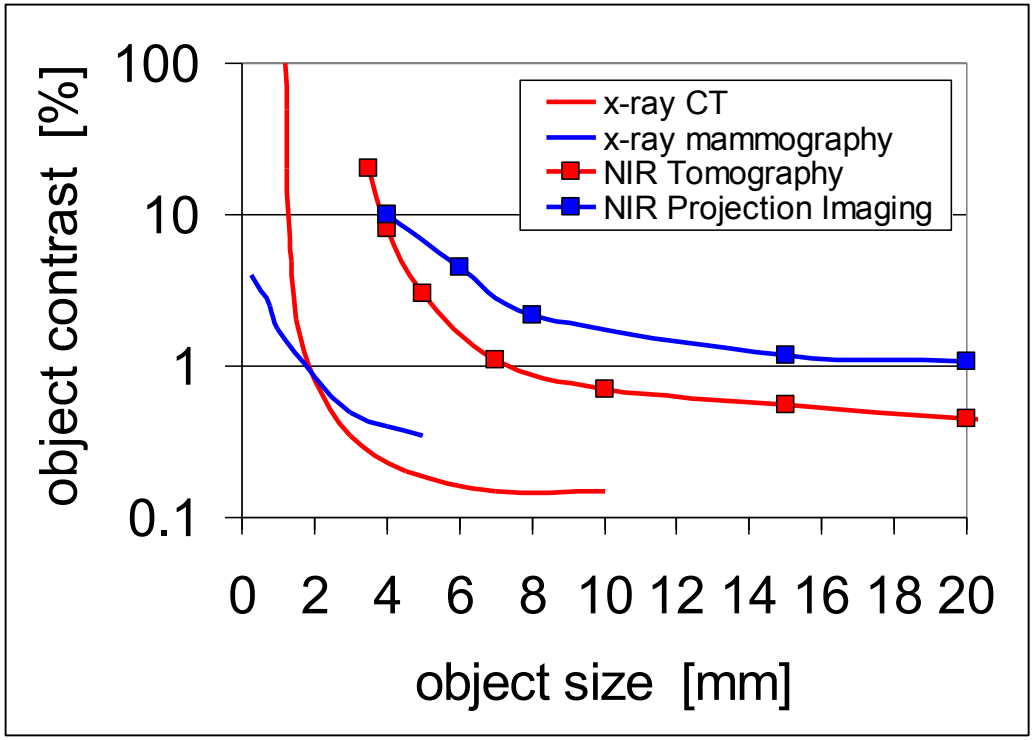
Viscoelastic effects
Athropomorphic artifacts
Imaging systems compatibility

**Very Useful in each situation**

# Contrast-Detail Phantoms






Pogue et al, Med. Phys. 2000.

Pogue et al, J. Biomed Opt. 2006.

# Key Issues in Phantoms for Imaging & Spectroscopy Systems

Repeatability
Standardization

Spatial Uniformity
Contrast Resolution

Viscoelastic effects
Athropomorphic artifacts
Imaging systems compatibility

**Science & R&D**

# MR/CT Compatible Phantoms:

hemoglobin, water, lipid, scatter ($TiO_2$), Gd-DTPA

gelatin

w. blood

CT/MRI scan

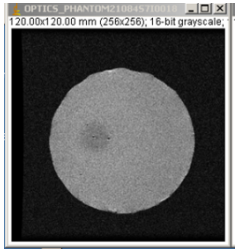
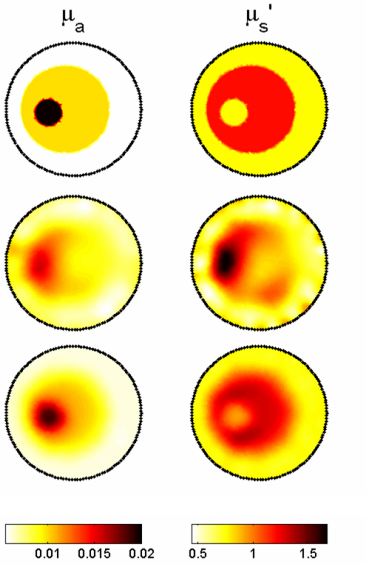
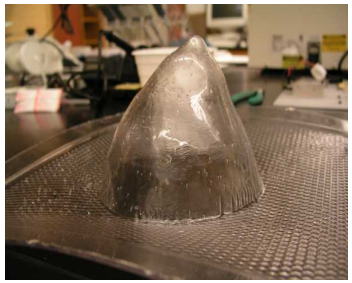
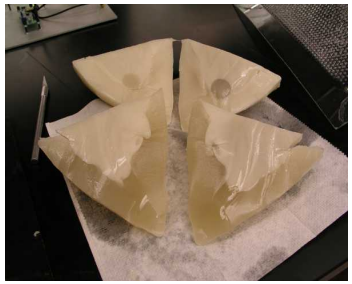
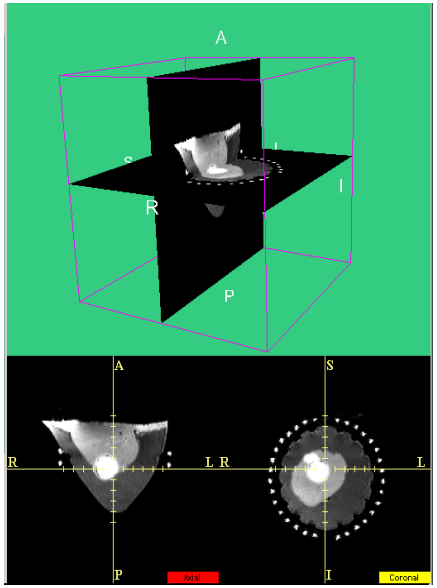


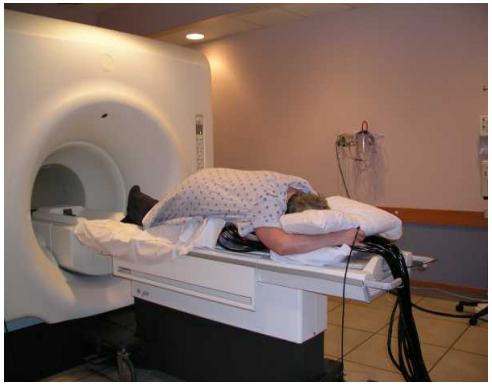

Image testing

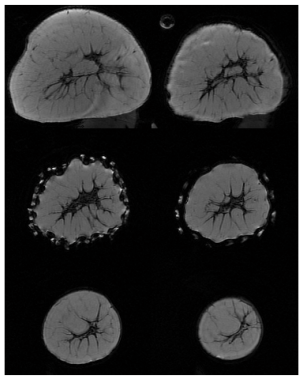








# Summary

- **Currently** → Voluntary & User developed
- **System validation** → NIR companies have solid phantoms
  (INO, NIRx, PerkinElmer, Mod. Imag., etc)
- **FDA approval?** → systems might ideally require
- **Pathways exist** → present CT/MRI/US/PET companies

Journal of Biomedical Optics 11(4), 041102 (July/August 2006)

# Review of tissue simulating phantoms for optical spectroscopy, imaging and dosimetry

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Thayer School of Engineering
Hanover, New Hampshire 03755

**Michael S. Patterson**
Juravinski Cancer Center
Department of Medical Physics
Hamilton, Ontario, Canada
and
McMaster University
Hamilton, Ontario, Canada

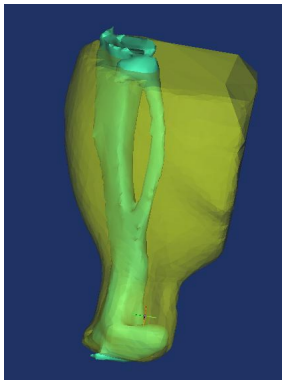
**Abstract.** Optical spectroscopy, imaging, and therapy tissue phantoms must have the scattering and absorption properties that are characteristic of human tissues, and over the past few decades, many useful models have been created. In this work, an overview of their composition and properties is outlined, by separating matrix, scattering, and absorbing materials, and discussing the benefits and weaknesses in each category. Matrix materials typically are water, gelatin, agar, polyester or epoxy and polyurethane resin, room-temperature vulcanizing (RTV) silicone, or polyvinyl alcohol gels. The water and hydrogel materials provide a soft medium that is biologically and biochemically compatible with addition of organic molecules, and are optimal for scientific laboratory studies. Polyester, polyurethane, and silicone phantoms are essentially permanent matrix compositions that are suitable for routine calibration and testing of established systems. The most common three choices for scatters have been: (1.) lipid based emulsions, (2.) titanium or aluminum oxide powders, and (3.) polymer microspheres. The choice of absorbers varies widely from hemoglobin and cells for biological simulation, to molecular dyes and ink as less biological but more stable absorbers. This review is an attempt to indicate which sets of phantoms are optimal for specific applications, and provide links to studies that characterize main phantom material properties and recipes.  [DOI: 10.1117/1.2335429]

Keywords: tissue simulating phantoms; optical spectroscopy; imaging; dosimetry.

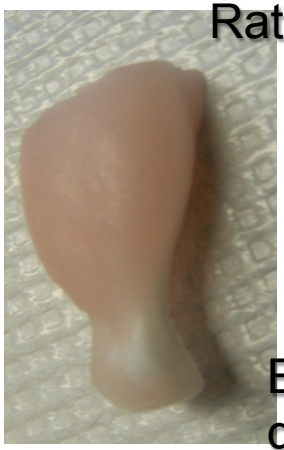
Paper 05287SSR received Sep. 30, 2005; revised manuscript received Jan. 10, 2006; accepted for publication Jan. 11, 2006; published online Sep. 1, 2006.

# Anthropomorphic Leg/Arm Phantoms for shape & biochemistry

## for Raman Tomography of bone mineral



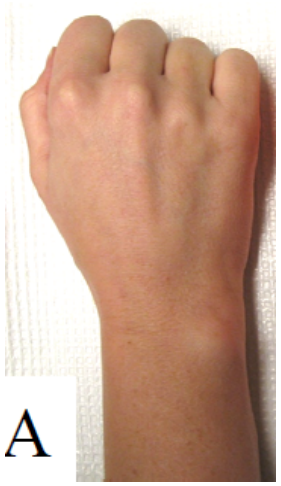
Gelatin over bone



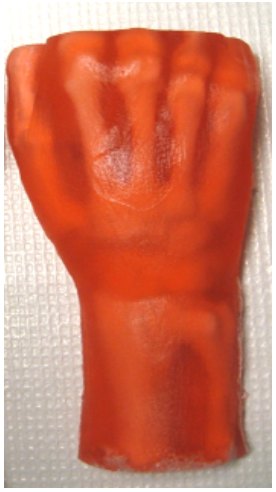
Rat tibia phantom

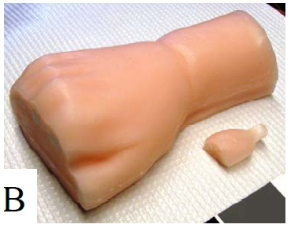
Blood + Intralipid in gelatin

CT scan → mold



A





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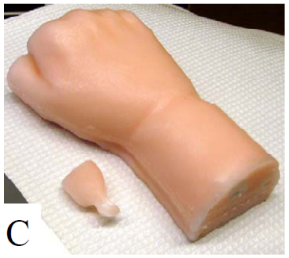

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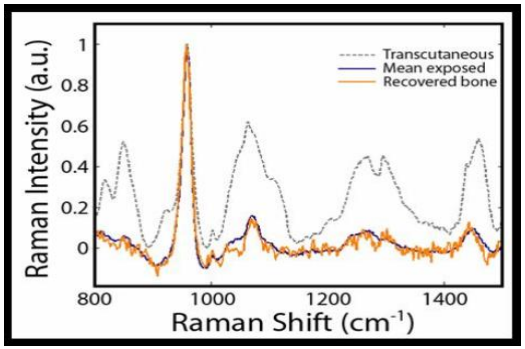


Esmonde-White et al, Analyst, 2011