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Initial investigation of a novel phantom for simulating optical scattering of dosimetric gels

S. G. Bosi, P. Naseri and C. Baldock

Institute of Medical Physics, School of Physics, University of Sydney, NSW 2006 Australia

1. Rationale

To evaluate the performance of an optical CT scanner for scanning dosimetric gels, it is useful to have a gel phantom in which the 3-dimensional shapes and extinction (attenuation) coefficients of the internal features can be manufactured at will. The obvious approach is to produce a phantom directly by conformal irradiation of a dosimetric gel. However, there are advantages to artificially creating features in a radiation insensitive phantom without using a clinical radiation source. Such a phantom is more stable over time, making it reusable indefinitely. Boundaries in an artificial phantom can be made sharper and optical extinction coefficients can be made more uniform, making evaluation of an optical-CT scanner simpler and more certain. Oldham et al [1] produced such a phantom by moulding finger-shaped cavities in gelatine and then backfilling the cavities with gelatine containing food-dye to simulate regions of differing optical extinction coefficient.

The main mechanism of light attenuation (extinction) in dye-based phantoms is optical absorption, so they would be best suited to simulating optically absorbing gels such as Fricke gels. However, the main mechanism of optical extinction in polymerising gels is by light scattering. Scattering behaves somewhat like absorption, but there are several important ways in which it differs, so it is not ideal to simulate a scattering gel using an absorbing phantom. Also, in Oldham finger phantoms produced in our laboratory, food-dye was found to be mobile in gelatine, diffusing visibly within hours, causing sharp boundaries to become diffuse. Such a phantom could not be used in more than a single scanner calibration.

We describe and evaluate an improved version of the Oldham phantom, employing scattering gels.

2. Experimental

PAGAT [2] (and similar gels) rely on light scattering by radiation-polymerised clusters of roughly colloidal size, so these gels exhibit opalescence typical of a non-absorbing colloid. They are milky, turbid in appearance, orange/red in transmission while internally scattered light is slightly blue. A simple way was found to simulate this opalescence in gelatine. Solutions containing dissolved oils will often produce a turbid colloidal suspension of insoluble oil droplets when added to water. A readily available commercial antiseptic liquid was found to produce a turbid suspension when added to melted gelatine. The turbidity was retained upon solidification. Boundaries between turbid and clear regions of gel exhibited no visible interdiffusion after 3 months at room temperature. The turbidity bore a strong resemblance to exposed PAGAT gel in transmission and reflection. The degree of turbidity could be controlled by mixing melted gelatine and the antiseptic in known proportions.
Gelatine powder (300 bloom porcine) and water were mixed in the proportions 52.6 grams of powder per litre of water to produce the base gel. A finger phantom was produced using a similar procedure to Oldham's [1]. However, the finger cavity was backfilled with layers of gel of increasing turbidity (Figure 1). The phantom was scanned using a Vista Optical CT Scanner (Modus Medical Devices Inc.). Scans were reconstructed using the accompanying software VistaRecon, were viewed and spatial profiles of optical densities (extinction coefficients) analysed using both the accompanying VistaView program (Figure 1(right) and Figure 2) and ImageJ (freeware supplied by the NIH). Modus Medical supplied a software plugin, VFF reader to allow ImageJ to interpret VistaRecon reconstructed images. Computed extinction coefficients, averaged over slices in the finger phantom, were plotted against concentration of antiseptic (Figure 3).

To determine extinction coefficients of the gels independently of the optical CT, 1 cm cuvettes were filled with gels spanning the same range of turbidity as in the finger phantom. Extinction coefficients (at the scanner wavelengths) were calculated from transmittances of these cuvettes which were measured in a CARY 5E UV-Vis-NIR spectrophotometer fitted with a Labsphere DRA-CA-5500 integrating sphere. Concentration of the antiseptic was expressed as grams of antiseptic liquid added per gram of clear melted gelatine and was used as a proxy for the as yet unknown concentration of the scattering particles.

Extinction coefficients obtained from the spectrometer were rescaled for comparison with those from the scanner. This is because the acceptance angle of the scanner camera is smaller than for the spectrometer because the camera is further from the specimen than in the spectrometer, so less scattered light is collected and the calculated extinction coefficient will be larger. This issue would not arise for absorption. In Figure 3, spectrometer extinction coefficients were plotted alongside those for the finger phantom for comparison.

3. Results and discussion
Comparison of spectrometer and phantom extinction coefficients (Figure 3) reveals the importance of calibrating with phantoms manufactured without radiation. In the plot, the phantom extinction coefficient appears to saturate at high turbidity, but this effect is not seen in the spectroscopic data from 1 cm cuvettes. This saturation is largely a result of the fact that where extinction is high, transmittance through the 2.5 cm thick finger is negligible. However, the outside of the finger is illuminated by scattered light from the surrounding gel which the reconstruction program would

**Figure 1.** Finger phantom with layers of increasing turbidity photographed in reflection (left), transmission (centre) and as a reconstructed optical CT image (right).
interpret as transmittance, thereby underestimating extinction coefficient. This effect should approach a constant saturation value. One cm cuvettes in the spectrometer would be far less susceptible to this. This effect would also contribute to the strong "dishing" artefact seen in the inset profiles in Figure 2, in which regions deep within a highly turbid region seem to exhibit lower extinction than the outer shell. Had these experiments been conducted with irradiated gels alone, saturation of extinction coefficient might have been interpreted as the degree of radiation induced polymerisation saturating. Turbidity here is controlled and constant over the width of the finger so it is clearly an optical artefact that must be avoided in dosimetry. Similarly, had dishing occurred at the outer edges of an irradiated phantom, it might have been interpreted as beam hardening. These effects reveal that gel sensitivity must be carefully matched to the expected doses quite apart from considering saturation level of polymerisation. Further investigation using these phantoms should result in a series of criteria for determining the optimum sensitivity of scattering gels.

**Figure 2.** VistaView image of finger cross-sections of regions of low (left) and high (right) turbidity. Inset plots show extinction coefficient profiles along a line through slices of the finger phantom. The more turbid region shows a strong dishing artefact.

**Figure 3.** *Left:* Determination of mean extinction coefficient ($\Delta$) for a circular selection within single slice of the finger phantom (using ImageJ). *Right:* Comparison of extinction coefficient versus concentration from spectrometer measurements and from reconstructed image of finger phantom.
4. References

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