Absolute calibration of polymer gel dosimeters using scintillating fibers

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1. Introduction
Accurate dose distributions are still difficult to obtain using polymer gel dosimetry. While the causes for observed discrepancies are being tracked and understood in details, solutions remain elusive. Causes for discrepancies in absolute dose distributions obtained by polymer gel dosimetry include imaging artefacts [1-4] and errors associated with the calibration procedure [5,6]. The temperature rise in polymer gel dosimeters upon irradiation was measured to vary depending on the material surrounding the gel sample [7]. Since the rate of polymerization (the kinetics of the polymerization reaction) can vary as a function of the temperature, it was argued that such changes could potentially lead to a difference in the amount of polymer formed (i.e., the extent of polymerization) [8]. Together, these simulations and experimental measurements make a clear case on the need to find adequate calibration procedures to improve the accuracy of dose distributions in polymer gel dosimetry.

Scintillation materials have been used as radiation detectors for several years [9] and they were introduced in radiation dosimetry in the early 1990s [10]. Such detectors have numerous advantages; they can have a very small detection volume, are water-equivalent (the medium of reference in radiation therapy), and are independent of temperature, pressure and dose rate [10,11]. Moreover, the scintillation process is independent on the incident radiation energy as long as the energy of the electrons causing the scintillation process is above 150-200 keV [9]. Finally, scintillation fiber detectors for radiation dosimetry cost only a few cents per mm.

In this preliminary study, we wanted to verify whether scintillation fiber detectors could be used to improve the accuracy of dose distributions determined by polymer gel dosimeters.

2. Materials and Methods
The sensitive region of scintillating detectors was a 3 mm long and 1 mm thick piece of scintillating fibers. The blue emitting BCF-12 (Saint-Gobain Crystals and Detectors, Paris, France) multiclad scintillating fiber was used for its relatively high light output. Each scintillator was coupled to a plastic optical fiber 1.5 m long and 1 mm in diameter. The surface of both the scintillating fiber and the optical fiber were polished with aluminum oxide polishing sheets of 1 µm prior to the coupling. The scintillating fiber was inserted in a 6 mm long polyethylene tube with an opening of 1 mm. Then a
A drop of cyanoacrylate glue was placed on the surface of the optical fiber before its insertion in the polyethylene tube, in contact with the scintillating fiber.

Scintillation dosimeters were calibrated using a cobalt source. The output of the optical fibers was placed in front of a color CCD camera (Apogee Alta U2000c, Apogee Instruments, Inc., Auburn, CA). During the irradiation of the detectors, 10 images were acquired during 15 s each. For each pixel position, the comparison between the 10 images allowed to remove spontaneous bad pixels resulting from the impact of scatter radiation on the CCD chip. After this noise filtration, the images were averaged to reduce statistical variations and a dark image (i.e. an image acquired with no incident light on the camera) was subtracted to remove the effect of dark current and possible light contamination. A second set of images was then acquired with the scintillating detectors irradiated with a 20 × 20 cm² field. This series was processed in the same manner as previously described. The light intensity produced in a given detector was evaluated by integrating the light spot produced by that detector on the image. Undesired Cerenkov light is produced inside the irradiated optical fiber and superimposes over the scintillation light. To remove the Cerenkov light and to obtain the calibration factors for the fibers, a chromatic discrimination technique was used [12]. This approach requires a color sensitive measurement with two different lengths of optical fiber irradiated (the 20 × 20 cm² and the 5 × 5 cm² fields).

Normoxic polymer gel dosimeters were prepared using a standard procedure. Briefly, 5% gelatin was soaked in water at room temperature for 15 minutes, heating was turned on and stabilized at 45°C. Three percent N,N’-methylenebisacrylamide and 3% acrylamide were added while the solution was continuously stirred. After complete dissolution, the solution was cooled to 30°C by placing it in an ice-water bath. Ten mM of tetrakis (hydroxymethyl)phosphonium chloride (THPC) was added. The solution was poured in 18 plastic vials for calibration purposes and inside a cylindrical glass bottle. The calibrated fiber detectors were inserted inside the bottle, which was subsequently placed in a refrigerator for 60 minutes to set.

The dosimeter gel calibration vials were irradiated with 6 MV photons from a linear accelerator. The phantom was irradiated with a cobalt source through a 45° filter in order to obtain a linear dose variation across the length of the bottle. In the middle of the bottle, where the second scintillator is located (see Fig. 1), the planned dose was 10.0 Gy.

The samples were placed in the head coil a birdeage head coil in a Siemens Sonata scanner (1.5 T). The parameters of the multi-slice multi-echo sequence were: FOV 150 mm x 113 mm, 24 echoes, echo spacing of 40 ms, TR 7750 ms, matrix 256 x 192, 32 averages, 8 slices, thickness 4 mm. A monoexponential function was used to fit the data of the last 22 echoes on a pixel-by-pixel basis. The

![Figure 1](image-url)  
*Figure 1.* Absorbed dose determined by polymer gel dosimetry and scintillating fiber detectors.
calibration curve from the small vials was used to convert the $T_2$ maps into dose maps.

3. Results and discussion
Figure 1 shows the absorbed dose as determined from the scintillating fibers and from the polymer gel dosimetry experiment. Since the dose at the location of the fibers cannot be determined by polymer gel dosimetry, the dose in front and at the back of the scintillator were averaged, assuming a linear dose change. It is apparent that the absorbed dose determined by the polymer gel dosimeter is lower than what was determined with the scintillating fibers. In a separate series of experiments, we found that only the first pixels around a fiber were affected, either by a partial volume effect or a susceptibility artefact.

4. Conclusion
In this preliminary study, we have shown that scintillating fiber detectors could be inserted in dosimeter gels and an accurate dose could be obtained. The dose determined by the polymer gel dosimeter appears to be underestimated, which could result from the calibration procedure making use of small calibration vials. Our next objective is to verify whether a correction derived from the fiber measurements could be applied to correct the calibration curve obtained from the polymer gel dosimeter. We will compare those results with planned dose distributions.

5. References
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