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# Gel Dosimetry By Medical Imaging Modalities And Future Of Molecular Imaging

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**ABSTRACT**

All branches of basic sciences such as anatomy, biology, physiology, and biochemistry were very important for medical students in clinic and treatment. However, when it comes to diagnostic imaging, there is a heavy reliance placed on tutelage regarding anatomically-based techniques while molecular and functional techniques are often given scant attention. Most clinicians are therefore very comfortable with using computerized tomography (CT), X-rays, ultrasound and magnetic resonance imaging (MRI) because the output is readily understood, particularly if the images are accompanied by judiciously placed arrows demonstrating the abnormalities, and which resembles sufficiently the mind's eye perception of a skeleton to pass as an anatomical representation, have often failed to capture the imagination of the clinician. There is a feeling that functional imaging is somehow less valid than radiological techniques because of the lack of fine spatial resolution. In order to, Polymer gel dosimeters are fabricated from radiation sensitive chemicals which, upon irradiation, polymerize as a function of the absorbed radiation dose. These gel dosimeters, with the capacity to uniquely record the radiation dose distribution in three-dimensions (3D); have specific advantages when compared to one-dimensional dosimeters, such as ion chambers, and two-dimensional dosimeters, such as film. The 3D radiation dose distribution in polymer gel dosimeters may be imaged using CT, ultrasound, optical-computerized tomography (optical-CT) or MRI. The fundamental science underpinning polymer gel dosimetry is reviewed along with the various evaluation techniques that in review were described.

**Keywords**: Gel dosimetry; medical imaging; molecular imaging

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## INTRODUCTION

### CT Imaging

X-ray computerized tomography (CT) imaging is proving to be a viable modality for the extraction of quantitative dose information from irradiated polymer gels and research in this area is increasing [1, 2]. Recent investigations have included: studies on the use of normoxic gels in conjunction with CT imaging; modeling the effects of gel polymerization on the resulting CT dose response; post-acquisition image filtering for CT polymer gel dosimetry; investigation of CT imaging technique for gel dosimetry; and the use of polymer gels to quantify x-ray CT dose during clinical CT scans [3-5]. One unresolved issue in CT gel dosimetry is the potential for gel polymerization due to the CT imaging process and possible effects of this polymerization on the dose distribution recorded by the gel [6-8]. The objective of the current study is to establish the magnitude of changes in gel CT numbers that could result from reading out active polymer gels with x-ray CT [7, 9]. This is achieved by: I) determining CT doses delivered to gels for typical gel imaging protocols and II) determining the response of polymer gel to kV irradiation. Researchers utilize the concept of computed tomography dose index (CTDI) and ion chamber measurements to quantitate the dose (slice) imparted to gels for volumetric (3D) CT imaging [10, 11].

Film measures of slice profiles in conjunction with the CTDI measures use to quantitate CT dose for single slice, region of interest (ROI) gel imaging [10, 12]. Large volume (i.e. 16 cm diameter) and small calibration (i.e. 2 cm diameter) phantoms as well as a range of scanning protocols are investigated [13, 14]. Hilts et al were to investigate the feasibility of using x-ray computed tomography (CT) for performing PAG dosimetry. Preliminary observations of dose contrast in CT images of irradiated PAGs have been made as well as preliminary reports on actual x-ray CT-based dosimetry techniques [15, 16]. Results suggest that CT can be used to extract dose information from PAGs, thus providing a relatively inexpensive and accessible means to analyze PAG dosimeters in a clinical environment [17, 18]. The protocol involves optimizing CT imaging parameters, maximizing the image signal to noise ratio and removing artifacts from the images. Employing this imaging protocol, the CT number–dose response of a PAG dosimeter is characterized and used to extract dose information from an irradiated gel [19, 20].

Also, this dose information is compared with that obtained using MRI and a comparison is made between MRI and CT PAG dosimetry techniques. The change in linear attenuation coefficient is mainly attributed to a change in electron density originating from the expulsion of water in the polymer clusters [21, 22].

### Ultrasound (US) Imaging

It was found that ultrasonic properties such as the acoustic speed of propagation, ultrasonic absorption and ultrasonic attenuation change with radiation-induced polarization in polymer gel dosimeters [23]. Changes in ultrasonic speed to absorbed dose for PAG and MAGIC gel dosimeters are related to both changes in the elastic modulus on absorbed dose and on changes in mass density. For PAG the changes in mass density with absorbed dose were the predominant factor [23]. The changes in ultrasonic properties with absorbed dose enable the use of ultrasound imaging. The ultrasonic absorption may be correlated with relaxation mechanisms active over a broad range of ultrasound frequencies such as interactions between water and polymer via hydrogen bonding and proton transfer and relaxation associated with motion of polymer side groups [24, 25]. A prototype tomographic ultrasound system is constructed that consists of a translation and rotation table onto which the phantom is suspended, an ultrasound transducer and a needle hydrophone [26]. The phantom and ultrasound components are immersed in a water bath to avoid attenuation in air. Ultrasonic pulses are transmitted by the transducer and received by the needle hydrophone. From the time difference and amplitude difference of the transmitted and received pulses, a time-of-flight (TOF) and transmission signal can be derived [27]. By rotating and translating the phantom with respect to the transducer and hydrophone several tomographic projections are obtained. From these tomographic projections, TOF and transmission images can be produced by filtered back projection. The image quality of the TOF image is better than that of the transmission image, although the contrast between the unirradiated and irradiated part is higher in the transmission image [19]. Artifacts in the transmission image are predominantly due to an acoustic impedance mismatch between water and gel phantom. There is much

room for improvement of image quality by matching the acoustic properties of the matching fluid, by the use of more sophisticated acoustics components and improvements in the alignment of the system [28].

**OCT Imaging**

In 1996 Maryanski et al [29] introduced a new method of 3D dosimetry using optical-computed-tomography, or optical-CT, to scan tissue equivalent gels that exhibited radiation-induced polymerization when exposed to high energy ionizing radiation. A dose response amenable to optical measurement was reported, arising from the production of light scattering micro-particles from radiation induced polymerization of acrylic monomers dispersed in the gel [30]. Unirradiated gel was virtually transparent, but irradiated gel became increasingly opaque with dose as the number density of scattering microparticles increased. The partial transparency of the gel lends itself to optical scanning by optical-CT, a technique analogous to first generation x-ray CT, except that a visible light source is used instead of an x-ray source [27].
magnetic resonance imaging (MRI)

It was demonstrated tree decays ago that MRI could be used to measure the dose distributions produced by ionizing radiation absorbed in tissue-equivalent gels [31]. Until recently the implementation of this concept has been limited to aqueous gels infused with the Fricke ferrous sulphate dosimeter solution [32]. In these so-called Fricke gels, free radicals produced by the radiolysis of water oxidize ferrous ions to ferric. As ferric ions produce a stronger paramagnetic enhancement of the water-proton NMR relaxation rates, their distribution may be determined by MRI [31]. The usefulness of this concept for clinical dosimetry was promptly recognized and several reports have appeared to date describing practical applications and further developments of the technique [33]. This system is based on radiation-induced polymerization and cross-linking of acrylic monomers which are uniformly dispersed in an aqueous gel. The formation of cross-linked polymers in the irradiated regions of the gel increases the NMR relaxation rates of neighboring water protons [31]. Therefore, the radiation-induced polymerization in polymer gels plays a role similar to that of the radiation-induced oxidation of ferrous ions in Fricke gels, but with four important advantages. First, whereas in Fricke gels ferric ion diffusion leads to significant blurring of the images of radiation fields within minutes after irradiation [31, 34], in polymer gels the spatial distribution of NMR relaxation rates, which reflects the distribution of dose, is stable and does not change with time [34]. Therefore polymer gels may be imaged at any time after irradiation, which is more convenient and results in greater accuracy, particularly in regions of a high dose gradient. Second, Fricke gels have an intrinsically high electrical conductivity caused by the presence of ions from sulphuric acid, sodium chloride and ferrous sulphate, each at a concentration of the order of 1mM or more [32]. Consequently, the RF field is strongly attenuated in these gels, producing significant variations of the RF pulse flip angle throughout the gel volume and decreasing the signal-to-nose ratio, both of which impair the accuracy of dose measurements based on MRI relaxation data [35]. By contrast, the polymer-gel dosimeters do not contain ionic species and show insignificant RF attenuation. Third, polymerized regions can be seen visually, as the cross-linked polymer is insoluble in water and precipitates from the aqueous phase of the transparent gel, which therefore becomes increasingly opalescent (and ultimately white) as the radiation dose increases [35]. Therefore the gel can also be used for qualitative testing by visual inspection, and possibly, with the use of an optical densitometer, in quantitative measurements. Fourth, polymer gels are considerably more sensitive to radiation than the Fricke gels, as verified below [24]. Moreover, their sensitivity increases with the magnetic field strength, as opposed to the Fricke system. Therefore, at higher imaging fields, which are increasingly common in clinical practice, the polymer-gel system should be both more accurate, due to an increased signal-to-noise ratio, and more sensitive.

## CONCLUSION

Optical-CT can provide a low cost and attractive alternative to MRI scanning of polymer gels for many applications. It was noted that MRI gel-dosimetry retains unique abilities in that it can image both arbitrary shaped gel-phantoms and phantoms containing opaque features. These situations may cause significant optical artifacts through reflection, refractions and absorbance. Polymer gels are relatively optically stable post irradiation. There is some post irradiation increase of polymerization with time, but diffusion, the overriding problem associated with Fricke gel dosimetry is not a significant problem. Optical-CT polymer gel dosimetry is a very sensitive technique that doses as low as 5 cGy could measure. Studies demonstrated the feasibility and benefit of modifying and matching the sensitivity of polymer gels and the delivered dose to the dynamic range

of the scanner. The dynamics of polymer gel dosimetry is now fairly well studied and understood. Investigations have concentrated on reactions times, linearity of response, tissue equivalence, dose response, manufacture repeatability, uniformity of response etc. While many researchers manufacture their own Polymer gels, both the polymer gels and optical CT scanners are now commercially available. The recent development of dry kits has significantly reduced the commercial cost of polymer gel. In contrast to other imaging modalities, MR scanning of polymer gel dosimeters provides many degrees of freedom. Several quantitative MR properties (such as T1 and T2) can be imaged and several different MR sequences can be used to acquire these properties. Whatever property or sequence is used to generate a quantitative parametric MR image data set, the accuracy and precision should be assessed and optimized using 'blank' phantoms.

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