

Dosimetry evolution in teletherapy: Polimer gel

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Abstract: Historical state of art dosimetry gel polymer and your evolution and chemical composition used in dosimetry.

Type	Composition
First gels	Folin's Phenol or Gallic Acid
Polymer Gel	Agarose and N,N'-methylene-bis-acrylamide
BANANA	Bis, acrylamide, nitrous oxide and agarose
BANG-1 TM	Bis, acrylamide, nitrogen and gelatin
BANG-2 TM	Bis, acrylic acid, sodium hydroxide, nitrogen and gelatin
BANG-3 TM	Bis, methacrylate acid, sodium hydroxide, nitrogen and gelatin
MAGIC	Methacrylate acid, ascorbic acid, gelatin and copper sulphate

Keywords: gel dosimetry, polimer gel, teletherapy dosimetry.

1. INTRODUCTION

Recently developed in radiotherapy techniques, such as the tridimensional planning (3D) treatment, Intensity Modulated Radio Therapy beam (IMRT), radiotherapy (conformational and conventional), Images Guided radiation Therapy (IGTR) and stereotactic radiosurgery have been increase the oncologic treatment complexity by radiation. All these techniques are used to reduce the treatment toxicity generated by means of the dose optimization in the target volume, radiosensitive irradiation minimizing, healthy structures or adjacent to tumor area [1].

However, irradiation reducing area to nearest to the target volume, the treatment accuracy system is increased as well as the dose deposited in the tumor area volume. Therefore reliable programs are necessary to systematically ensure

the high quality and confidence in the whole planning process, treatment and dose deposited in the target volume [1].

The current methods are radiotherapy dosimetry standards to dose distribution evaluation used film dosimetry, thermoluminescent dosimeters (TLDs), ionization chambers or photodiodes.

All of these are two dimensional methods for dose measurements [2]. These dosimeters will not measure the dose distribution in three dimensional space and only at certain points of analysis. Some dosimeters are energy and angular dependent beam radiation positioning for correct measurement [3].

Thus, the use of such detectors is also associated with additional problems: (i) large volume relatively, which prevents measurement

in high dose gradient regions and (ii) may be larger than the treated tumor volume. In certain treatment situations this characteristic limit of spatial dose resolution; (iii) detectors are not equivalent to the human tissues and (iv) some treatment types there is the possibility of radiation fields disturbing causing errors in the exposure rate measurement [4].

Therefore, in radiotherapy treatment centers system most frequently used in clinical dosimetry and that is capable of partially tracing 3D dose distributions is a position phantom filled with water and connected to point detector (ionization chambers or semiconductor detectors, for example). Unfortunately this system will be not allow complex dose distributions formed by the overlapping of different radiation beams, also full dose distribution measurement the in space [5–7].

2. HISTORICAL REVIEW

2.1. First polymer gels dosimetry forms

In 1950s, Day and Stein [8], the three dimensional dosimetry first forms appeared. The dosimeter had been developed observing an coloration alter after ionizing radiation interacting. The gel dosimeter had a chemical formulation, essentially presented a Folin's Phenol (gallic acid) reagent [8 and 9].

In 1954, Alexander et al. [10] discussed the ionizing radiation effects on polymethylmethacrylate. Therefore was first associated idea of gel polymeric systems dosimetry [9].

Andrew et al. [11] performed dose measurements associated with photons and electrons beams using agar gels associated with spectrophotometry [9].

A year later Hoecker and Watkins [12] developed an alternative study for gel dosimetry based on the radio induced monomers and

polymers polymerization in aqueous solution [9], [10, 12 and 13].

In 1961, Boni [14] developed a gel dosimeter using only polyacrylamide, that had been used as gamma radiation dosimeter [9 and 14].

2.2. Gel dosimetry

Three dimensional dosimetry presented a great innovation in the 1980s, when Gore et al. [15] associated the Fricke gel with magnetic resonance imaging (MR) for radiotherapy treatments dose distribution evaluation. Therefore this Fricke gel dosimetry form had recording dose values purpose through modified dosimeter that its molecular structure when interactions with X radiation.

The molecular alteration would be proportional to the dose applied, being possible to visualize the gel irradiated volume through the MR. This association has become a promising tool, which has requirements satisfied as ideal dosimetry system. Unlike the other dosimetry methods, MR associated with imaging Fricke gel dosimetry for gel irradiated is completely noninvasive and it is not necessary to remove some of the irradiated material for testing, because a radiation gel detector propriety [9, 13, 15 and 16].

Since then, the use of Fricke gel dosimeter association have been performed. Gum et al. [17] determined that for anthropomorphic phantoms containing inhomogeneous tissues, Fricke gel associated with MR was a powerful tool for the verification of radiotherapy treatment plans. The from phantom developed was anatomical area of the thorax, used of soft tissues simulation (lungs, heart and spinal cord) with Fricke gel with a low density. An average deviation was found less than 5% difference between virtually treatment planning and phantom planning applied, the difference was generated due to low magnetic resonance signal to noise ratio [17].

Oldberg et al. [18] demonstrated that the Fe^{+2} ion diffused in low density Fricke gel dosimeter (simulating lung tissues) was reliable for dose measurements absorbed in thorax simulated phantoms.

the Fricke gel dosimeter conducted by Chu et al. [19] where had a Fe^{+3} ions low diffusion. Thus, the gel was based on the polyvinyl alcohol and new hydrogels additions were developed as three dimensional dosimetry forms in radiotherapy. Due to its transparency, the Fricke hydrogel may have images generated by magnetic resonance imaging and optical tomography [19].

However, the greatest disadvantage in use the Fricke gel dosimetry is the fast diffusion process of ferric ions into dosimetric solution. Through this action occurs loss information process, which means a lower spatial resolution in the dose registred. This loss is greater how much spent time longer between Fricke gel irradiation and sample imaging [4 and 20].

2.3. Polimer gel dosimeter

Kennan et al. [7] describe dosimetric solution irradiation as composed of agarose and N, N'-methylene-bis-acrylamide, observed R1 and R2 ratios relaxation of the material when submitted to MR increased proportionally with the dose deposited.

However Maryanski et al propose the gel characteristics: (I) use of monomers derived from acrylic and cross linking agents; (ii) Gel solution based on agarose; (iii) Polymerized region dimensional stability [21 – 23].

Therefore a new gel dosimeter formulation was proposed by Maryanski. In chemical formulation the dosimetric solution had two monomers: acrylamide and N-N'-methylene-bis-acrylamide (Bis), which were diluted in aqueous agarose matrix. Thereby monomers would undergo the radio induced polymerization process. This system was called BANANA (due presence of its chemical compounds: N-N'-

methylene-bis-acrylamide, Acrylamide, nitrous oxide and agarose).

Polymer gels prepared with monomers such as acrylamide are currently used in biochemistry as field for protein electrophoresis and nucleic acids separation, typically, present: acrylamide monomers and a cross linking agent, known as Bis (N-N'-methylene-bis-acrylamide).

Gels polymerization process used for electrophoresis is generally initiated and chemically controlled using a free radical initiator, such as PSA (ammonium persulfate). However, the polymerization can also be induced by radiation through the production of a free radical generated during water radiolysis [5, 7 and 12].

BANANA gel (composed of N-N'-methylene-bis-acrylamide, acrylamide, nitrous oxide and agarose) was the gel polymer developed first form. In this type of gel polymer, acrylamide and N-N' were added in gelatin of the agarose type. Sequential works utilized gels polyacrylamide (PAG) and BANGTM. The development of the BANGTM gel resulted increasing sensitivity of the gelatinous radiation fields solution. Nitrous oxide or nitrogen is added to the chemical solution expelling oxygen during organic dosimeter preparation period [24].

The BANG 1TM gel uses acrylamide powder form, BANG 2TM gel replaces acrylamide powder by acrylic acid and sodium hydroxide as the buffer solution for the pH of the solution. The response of the BANG 2TM gel when subjected to magnetic resonance imaging is high than the BANG 1TM gel, which means that the relaxation ratio of the spins of the water molecule is higher per dose unit [24 and 25].

BANG 3TM gel type has superior response to the BANG 2TM type gel in magnetic resonance imaging [26]. BANG 3TM gel acrylic acid is replaced by methacrylate acid [27].

After irradiation, the gel may contain polymerized and cross linked regions. This is the spatial dose response origin characteristics of the gels with the polymerization dependent degree on the amount of free radicals generated by the incident radiation and therefore absorbed dose.

Polymerized regions certain water molecules clusters alter their linking state. This can be investigated using the magnetic resonance relaxation time characteristics (in images generated through the longitudinal relaxation time - T1 or through images generated by the transverse relaxation time - T2) [2, 23, 27 and 28]. Computed tomography X rays images (CT) generated can also be used where they are produced through measuring the different attenuation values generated by effective atomic number significant changes of the polymerized region [30].

The sensitivity (i.e., the change in the relaxation time in MR or the value CT effective atomic number) and the polymer gel dosimeters saturation limit critically depend on the conditions during gel preparation. Factors such as: (i) exposure to light and oxygen during the preparation period, (ii) fraction of monomers and gelatin by total weight final solution and (iii) the temperature during the period of acquisition of MR or CT images are some conditions that influencing the sensitivity of the dosimeter [2, 25 e 29].

Normoxics: Due to the free radicals nature produced by the radiation interaction with the gels polymer, these must be a hypoxic material, that is, with an infinitesimal presence of oxygen ($1 / 1,000,000$ – oxygen / dosimetric solution) in chemical composition. This process is given by oxygen being highly reactive chemical element, which when present in large quantities in hydrogel will inhibit the polymerization process [13].

Through the work produced by Fong et al. [31], the gels polymer dosimetry has undergone a significant development, a new chemical composition produce this new gel dosimeter type as known MAGIC uses (i) a chemical agent that realizes the free oxygen capture in aqueous solution and (ii) another chemical agent that will form with the oxygen molecule captured in (i) chemical bond that will result in an organometallic complex in solution.

In this way, the oxygen does not inhibit the radiation induced polymerization process. Another advantage presented by normoxed gels is that they can be prepared under normal ambient conditions not requiring a glovebox, as it happens with PAG gels for their preparation [30 and 31].

The MAGIC gel formulation consists of methacrylic acid, ascorbic acid, gelatin and copper sulphate. The ascorbic acid binds with free oxygen in the gelatinous matrix, an organometallic complex is then formed with the copper sulphate. The Deene et al. [33] demonstrated that other antioxidants can be used to the capture of the free oxygen present in the dosimetric solution [33].

With new class hydrogels studies introduction by MR have been developed to behavior investigate of these materials when submitted to radiotherapy techniques (e.g. IGRT or VMAT) [9 33 and 34].

3. FINAL CONSIDERATIONS

Through gel polymer association to simulating object (or phantom) can be ensured quality, confidence and accuracy during the planning, treatment and dose deposited in target volume. The hydrogel presents equivalence to human tissue and greater temporal and dimensional stability in the dose register when compared to Fricke gel dosimetry as observed by

MARYANSKI et al. [21, 23 and [25], DEENE et al. [36], BALDOCK et al. [9 and 13].

The gel dosimeter new chemical composition (derived from the nPAG family) and doses absorbed response behavior by the dosimetric solution to the energy ranges used in radiotherapy treatments according ISO 4037 [37].

The radiotherapy treatment new modalities bring greater accuracy and safety in the techniques used by teletherapy. However, due to its greater complexity mainly in dose deposition relation in tumoral mass the two dimensional dosimetry is not able to perform this analysis satisfactorily [35].

As such we observed that the dosimetry by polymer gels has also evolved since first applications. Therefore this dosimetry form is a promising tool because its associated with MR or CT. Can perform the isodose mapping curves for volume given according to the techniques used for irradiation demonstrating register capacity for three dimensional dose which can't see at radiographic films and ionization chambers dosimetry.

The gel dosimetry also demonstrates to be efficient dosimeter for registred and complex dose distribution evaluation and can be an efficient tool for validation of treatment plan, dose delivery systems and patient positioning procedures along the linear accelerator.

Another gels dosimeter important feature is the stability after irradiation. The macroscopic diffusion of products generated by X radiation through the gelatinous matrix is negligible and the registered dose distribution is stable for long periods of time (weeks, months and even years), it is not necessary removing gel polymer parts irradiated and polymerized to perform dosimetric tests, because the dosimetric system itself corresponds to detection system [21 and 25].

When simulator object filling with a gel dosimeter is taking: (i) tool along with an

international standards protocol based ISO 4037 [37] that will evaluate what has been planned through patient treatment software, (ii) can be tool for certification of clinics and radiotherapy hospitals in relation to determination radiation oncology treatments and, finally, (iii) develop the culture of total volumetric dosimetry with hospitals and radiotherapy clinics, as well as the competent entity and organs.

The final result of the factors (i), (ii) and (iii) presented previously aims better quality control program, where the greatest beneficiary is the patient who will be performing a more reliable and efficient radiotherapy treatment.

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