Comparison of the effectiveness of polymer gel dosimeters (Magic and Pagatug) for organ dose calculation in brachytherapy, nuclear medicine and teletherapy

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Sent for review: 6 June 2017 Revised accepted: 7 October 2017

Abstract

Purpose: To investigate and compare two polymer gel dosimeters, Magic and Pagatug, as organ dosimeters for 3D measurement of dose distribution in brachytherapy, nuclear medicine and teletherapy.

Methods: Magic and Pagatug polymer gels were compared with soft tissue based on irradiation with low energy photons during therapeutic applications. Comparison was simulated using Monte-Carlo-based MCNPX code. ORNL phantom–Female was used to model some vital organs (kidneys, ovaries and uterus). The right kidney was proposed to be the source of irradiation and the two organs were exposed to this irradiation.

Results: The effective atomic numbers of soft tissue, Magic and Pagatug were 6.86134, 7.07 and 7.2884, respectively. The results showed that Magic and Pagatug, were comparable to soft tissue with regard to application in nuclear medicine and teletherapy. Differences between gel dosimeters and soft tissue were defined as the dose responses. This difference was < 8.1, < 4 and < 76.8 % for teletherapy, nuclear medicine and brachytherapy, respectively.

Conclusion: Due to slight differences between the effective atomic numbers of these polymer gel dosimeters and soft tissue, the polymer gels are not suitable for brachytherapy since the photoelectric interaction is dominant for low energy photons, and the interaction relates to Z4. The results demonstrate that the gel dosimeters are best suited for nuclear medicine.

Keywords: Magic, Pagatug, Brachytherapy, Nuclear medicine, Teletherapy, Organ dosimetry, Soft tissue

INTRODUCTION

There are several dosimetry techniques used to determine the distribution of radiation dose during radiation treatment. Each dosimeter tool has a set of unique advantages and disadvantages. Gel dosimeters are appropriate dosimeters for determining 3D dose distribution with high spatial resolution unlike conventional dosimeters such as radioactive ionization chambers, TLD cards and radiography films [1,2].

The TLD cards (also called mini ionization chambers) have some drawbacks in measuring very high doses with high dose gradients, due to their finite sizes which permit measurement of the dose only at a single point [1]. Film batches
can also offer 3D dose measurements by positioning film in multiple planes but accurate positioning of films in several layers can be a difficult and time-consuming process. Therefore, conventional dosimeters are suitable for clinical brachytherapy [3]. Fricke gel and polymer gel dosimeters are two different dosimeters which can give 3D dose distribution. However, polymer gel dosimeters maintain a high spatial integrity when compared with the Fricke gel dosimeters [4]. There are several different scans in nuclear medicine applications, of which heart scans are the most common. In these scans, the kidneys absorb the highest amount of dose as well as some other critical organs such as ovaries and uterus [5]. For this reason, the source positions are placed in the kidneys in brachytherapy, and the kidneys are radiated in nuclear medicine and teletherapy.

As stated earlier, polymer gels can be used in medical phantoms as valuable tools for determining 3D dose distribution in a medium. Polymer gel dosimeter can replace medical phantom materials as media with features similar to soft tissue. This type of dosimeter can be considered as a suitable option for studying dose distribution in sensitive organs during radiation therapy and nuclear medicine. The dose received in sensitive organs has important role during radiation therapy and nuclear medicine.

Therefore, in the present study, the capabilities of polymer gel dosimeters, Magic and Pagatug as medical phantoms for evaluating absorbed dose of radiation in the ovaries and uterus from the right kidney during brachytherapy, nuclear medicine and teletherapy were investigated.

**EXPERIMENTAL**

ORNL phantom-Female was chosen for this study. The phantom consisted of 3 materials and 40+ discrete cells that simulate the human body [6]. The radiation sources considered for brachytherapy, nuclear medicine and teletherapy are TC-99m [4], Co-60 [7] and 125I [6], respectively.

Table 1 shows the composition of the Magic and Pagatug polymer gel dosimeters, while Table 2 shows the elemental composition of ORNL phantom-Female.

**Simulation procedure**

In this study, MCNPX 2.6.0 was used for the simulations. F4 tallied with DFn, and DEn was used for dose measurement. Figure 1 shows simulated phantom (ORNL phantom–Female) in MCNPX code.

**RESULTS**

Outputs of simulations were determined for polymer gel dosimeters and soft tissue during brachytherapy, nuclear medicine and teletherapy, and the results are shown in Table 3 and Table 4.

Table 3 shows that the polymer gel dosimeters, Magic and Pagatug, are comparable to soft tissue for use in nuclear medicine and teletherapy. Differences between gel dosimeters and soft tissue were defined as the dose responses. This difference is < 8.1. < 4 and < 76.8 % for teletherapy, nuclear medicine and brachytherapy, respectively.
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Figure 1: Simulated phantom ORNL phantom–Female (15 Ovaries, 45 Kidneys and 64 Uterus)

Table 3: Output of simulations for polymer gel dosimeters during Brachytherapy, Nuclear Medicine and Teletherapy

| Type of source | Activity | Source position | Organ | Dose in | Error | Type of dosimeter | Density of | Difference | Soft tissue % |
|----------------|----------|-----------------|-------|---------|-------|-------------------|------------|------------|--------------|
| $^{125}$I     | 1110     | Right kidney    | Ovaries | 2.18E-2 | 0.0260 | Magic             | 1.095     | 68.5       |
| $^{125}$I     | 1110     | Right kidney    | Uterus  | 1.72E-2 | 0.0164 | Magic             | 1.095     | 73.3       |
| TC-99m        | 1110     | Right kidney    | Ovaries | 7.13E-2 | 0.0111 | Magic             | 1.095     | 3.4        |
| TC-99m        | 1110     | Right kidney    | Uterus  | 6.29E-2 | 0.0071 | Magic             | 1.095     | 3.1        |
| Co-60         | 188E+6   | Right kidney    | Ovaries | 6.94E-7 | 0.0587 | Magic             | 1.095     | -8.1       |
| Co-60         | 188E+6   | Right kidney    | Uterus  | 6.89E-7 | 0.0404 | Magic             | 1.095     | -1.4       |
| $^{125}$I     | 1110     | Right kidney    | Ovaries | 6.68E-3 | 0.0388 | Pagatug           | 1.0653    | 67         |
| $^{125}$I     | 1110     | Right kidney    | Uterus  | 5.57E-3 | 0.0227 | Pagatug           | 1.0653    | 76.8       |
| TC-99m        | 1110     | Right kidney    | Ovaries | 6.06E-2 | 0.0102 | Pagatug           | 1.0653    | 3.9        |
| TC-99m        | 1110     | Right kidney    | Uterus  | 5.30E-2 | 0.0061 | Pagatug           | 1.0653    | 3.5        |
| Co-60         | 188E+6   | Right kidney    | Ovaries | 6.33E-7 | 0.0569 | Pagatug           | 1.0653    | -8.1       |
| Co-60         | 188E+6   | Right kidney    | Uterus  | 6.30E-7 | 0.0405 | Pagatug           | 1.0653    | -1.5       |

Table 4: Output of simulations for soft tissue during brachytherapy, nuclear medicine and teletherapy

| Type of source | Activity | Source position | Organ | Dose in | Error |
|----------------|----------|-----------------|-------|---------|-------|
| Co-60         | 188E+6   | 100 cm away from right kidney | Ovaries | 6.89E-7 | 0.0557 |
| Co-60         | 188E+6   | 100 cm away from right kidney | Uterus  | 6.40E-7 | 0.0401 |
| $^{125}$I     | 1110     | Right kidney    | Ovaries | 4.00E-3 | 0.0228 |
| $^{125}$I     | 1110     | Right kidney    | Uterus  | 3.15E-3 | 0.0127 |
| TC-99m        | 1110     | Right kidney    | Ovaries | 5.83E-2 | 0.0046 |
| TC-99m        | 1110     | Right kidney    | Uterus  | 5.12E-2 | 0.0027 |

Table 5: Comparison between errors (%) of Magic and Pagatug Gel dosimeters

| Type of treatment | Max. error in using MAGIC | Max. error in using PAGATUG |
|-------------------|---------------------------|-----------------------------|
| Brachytherapy     | 68.5                      | 76.8                        |
| Nuclear medicine  | 3.4                       | 3.9                         |
| Teletherapy       | 8.1                       | 8.1                         |

The results demonstrate that the gel dosimeters are best suited for nuclear medicine.

Table 6, Table 7 and Table 8 show the ratios of photon interactions for the polymer gel dosimeters and soft tissue during brachytherapy, nuclear medicine and teletherapy. These results show that the dominant interaction in the polymer gel dosimeters and soft tissue for nuclear medicine and teletherapy was Compton interactions for the polymer gel dosimeters and soft tissue during brachytherapy, nuclear medicine and teletherapy.
(incoherent) scattering, while in brachytherapy, both Compton (incoherent) and photoelectric were the dominant interactions. The similarity in dominant interactions for the polymer gels and soft tissue shows a good agreement which is of interest for the dosimetry applications.

**DISCUSSION**

In this study, the capabilities of Magic and Pagatug polymer gel dosimeters for measuring 3D dose distribution during brachytherapy, nuclear medicine and teletherapy were evaluated by MCNPX code, and their dose responses were compared with soft tissue. These polymer gel dosimeters are capable of measuring complex 3D dose distributions with high spatial resolution, unlike other radiation dosimeters such as ionization chambers, TLD and radiographic films. The results showed that the dosimeters were more suitable for use in teletherapy and nuclear medicine when compared as opposed to brachytherapy. In brachytherapy the two gel
dosimeters had more than 10 percent error, which is not acceptable in brachytherapy. The difference observed between the gel dosimeters and soft tissue is related to incoherent interaction with 48.1 % deviation. In teletherapy, both Magic and Pagatug had similar errors and they were both reliable. Photoelectric interaction is the main cause of difference between polymer gels and soft tissue in teletherapy. In nuclear medicine, Magic has less error when compared to Pagatug, due to differences between their effective atomic numbers. The effective atomic numbers for soft tissue, Pagatug and Magic were 6.86134, 7.2884 and 7.07, respectively.

It is known that photoelectric interaction is dominant for lower energy photons and this interaction relates to atomic number as $A^4$ [10]. Since the effective atomic numbers of soft tissue and the gel dosimeters were different, larger errors would occur in lower energy photons. Hence, the dose response measurement error for Pagatug polymer gel was larger than that for Magic polymer gel.

**CONCLUSION**

The results obtained in this investigation strongly suggest that if low energy sources are required in therapeutic applications, Magic and Pagatug polymer gel dosimeters are acceptable soft tissue equivalent dosimeters.

**DECLARATIONS**

**Conflict of Interest**  
No conflict of interest associated with this work.

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### Table 8: Photon with polymer gel dosimeter and soft tissue interactions ratio for teletherapy

| Pagatug | Magic |
|---------|-------|
| **Flux (photon)** | **Reaction rate** | **Ovaries** | **Flux (photon)** | **Reaction rate** | **Ovaries** | **Flux (photon)** | **Reaction rate** | **Ovaries** |
| **Incoherent** | **Coherent** | **Pair Production** | **Total** | **Incoherent** | **Coherent** | **Pair Production** | **Total** | **Incoherent** | **Coherent** | **Pair Production** | **Total** |
| 9.08E-15 | 1.49E-15 | 0.00 | 1.61E-15 | 9.03E-15 | 1.49E-15 | 0.00 | 1.64E-15 | 9.08E-15 | 1.49E-15 | 0.00 | 1.64E-15 |
| 6.04E-17 | 6.18E-17 | 0.00 | 1.61E-15 | 6.74E-17 | 7.93E-17 | 0.00 | 1.63E-15 | 6.77E-17 | 7.91E-17 | 0.00 | 1.63E-15 |

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**Contribution of Authors**

The authors declare that this work was done by the authors named in this article and all liabilities pertaining to claims relating to the content of this article will be borne by them.

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