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Original research article

Improvement of sensitivity of X-ray CT reading method for polymer gel in radiation therapy

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ABSTRACT

Background: Three dimensional (3D) dosimetry methods are useful for advanced radiotherapy techniques such as stereotactic radiosurgery (SRS) and high dose rate (HDR) brachytherapy. Polymer gel is one of the more reliable 3D dosimetry techniques. More studies are needed to improve the efficiency of polymer gels for their application in dosimetry.
Aim: In the current study, the best protocol for reading of N-isopropyl acrylamide (NIPAM) polymer gel by X-ray computed tomography (CT) was implemented for application in radiotherapy.
Material and methods: The NIPAM gel was made and irradiated by 6 MV. Its reading was done by the X-ray CT after 24 h and the information examined by using the MATLAB software. In the present work, the different effects of slice thicknesses and voltages were investigated for its lower toxicity of NIPAM polymer gel. The results of a recipe of different filtering on the response curve of polymer gel was investigated.
Results: The measured dose sensitivity was $\Delta N_{CT}(H) = 0.29 \pm 0.01 \left(HGy^{-1}\right)$ for the NIPAM dosimeter. The best sensitivity was achieved for 120 kVp and the slice thickness of 10 mm. The greater slice thickness gained more desirable sensitivity. This process was repeated by using different filtering with different thicknesses to obtain the best sensitivity.
Conclusions: The sensitivity of X-ray CT reading technique of NIPAM Polymer gel depended on the slice thickness and kVp. The wiener2 filtering was useful to improving sensitivity.

1. Background

Cancer is currently one of the most important causes of death in the world. In recent decades, cancerous treatments have seen a remarkable progress; one of these common approaches is radiation therapy. The aim of radiotherapy is to provide dose to cancerous cells, so that the adjacent healthy tissues have the lowest radiation levels. Radiation therapy encompasses all the techniques that deliver enough dose of ionizing radiation into malignant tissues without causing a lot of damage to other healthy tissues. Therefore, in the treatment of cancerous masses, all efforts are made to minimize the possible damage to tissues around the target mass.[1–3] Accurate dosimetry is essential in the radiation therapy, especially in the modern techniques, such as stereotactic radiosurgery (SRS), intensity modulated radiotherapy (IMRT) and high dose rate (HDR) brachytherapy. The dosimeter is a device that measures absorbed doses. The most common detectors for radiation therapy are ionization chambers,[4] silicon diodes,[5] diamond detectors,[6] metal oxide semiconductor field effect transistors (MOSFETs),[7] radiographic, radiochromic films,[8] thermoluminescent dosimeters (TLDs) and polymer gels.[4,9] Dosimeters currently used, such as ionization chambers and thermoluminescent dosimeters, have limitations as they only measure the dose at one direction, and films are two dimensional (2D) dosimeters. One of the three dimensional (3D) dosimetry methods is polymer gel which is a valuable and reliable method to measure the spatial distribution of dose.[10] Polymer gel dosimetry is a 3D dosimetry technique for verification of distribution dose.[11] The amount of polymer formed is proportional to the absorbed dose. Therefore, in modern radiation therapy techniques, such as IMRT, SRS and 3D HDR brachytherapy, absorbed dose distributions could be measured by using polymer gel dosimeter. Another advantage of polymer gel dosimeters is that they have the same composition as the body tissue.[12] The amount of performed polymer gel can be measured with the different techniques such as magnetic resonance imaging (MRI),[13] optical computed tomography (OCT),[14] X-ray computed tomography (CT),[15,16] Raman spectroscopy[17] and ultrasound.[18] The advantages of the X-ray CT readout are the availability of CT in clinical radiation

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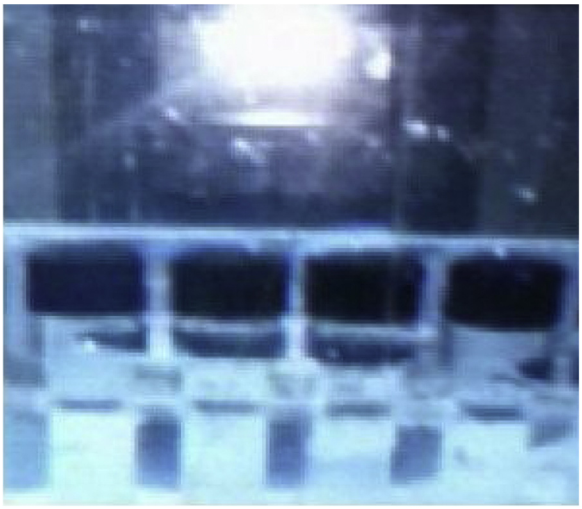

Fig. 1. The irradiated samples of NIPAM gel vials.

Table 1
Constituents and formulations of NIPAM gel.

Component	Weight Percent	Formula
De-ionized water	%89	H_2O
Gelatin	%5	*
N-isopropyl acrylamide	%3	$C_6H_{11}NO$
Bis	%3	$C_7H_{10}N_2O_2$
THPC	10 mM	$C_4H_{12}CLO_4P$

therapy and speed of image acquisition. The X-ray CT is a method for evaluation of polymer gel dosimeters due to a change in the linear attenuation coefficient with increasing dose.[19] The limitations of polymer gel are the toxic materials used in them. Contact of polymer gel with the skin can lead to abnormalities in the nervous system. Hence, gel must be built in an isolated environment. The NIPAM polymer gel has a lower toxicity than the previous polymer gels.[20] The NIPAM polymer gel could be made without any complex equipment. It is possible to use this gel for dosimetry of linear accelerator (LINAC) beams in radiotherapy.[21] In this work, the NIPAM polymer gel dosimeter with the X-ray CT reading was studied. The dependence of sensitivity of this reading method with several parameters of the X-ray CT, such as kVp, slice thickness and various filtering was investigated.

2. Aim

The dependence of CT number on dose was investigated in the NIPAM polymer gel dosimeter by using the X-ray CT to get the best sensitivity with the optimal protocol. And the recipe of different filtering with different thicknesses was assessed.

3. Materials and methods

3.1. Gel preparation

For this study, the NIPAM polymer gel was prepared according to the method reported by Senden.[22] Polymer gel was manufactured in cylindrical vials for readout by the X-ray CT. To make this gel, 5% of gelatin (skin gel strength 300, Type A) was added to 80% of de-ionized water. The amounts of 3% (NIPAM) monomer and 3% N, N'-methylene-bis-acrylamide (Bis) crosslinker were added. Then 10 mM tetrakis hydroxymethyl phosphonium chloride (THPC) solution was prepared with the remaining amount of water and stirred into the gel Table 1. Gelatin plays the role of keeping

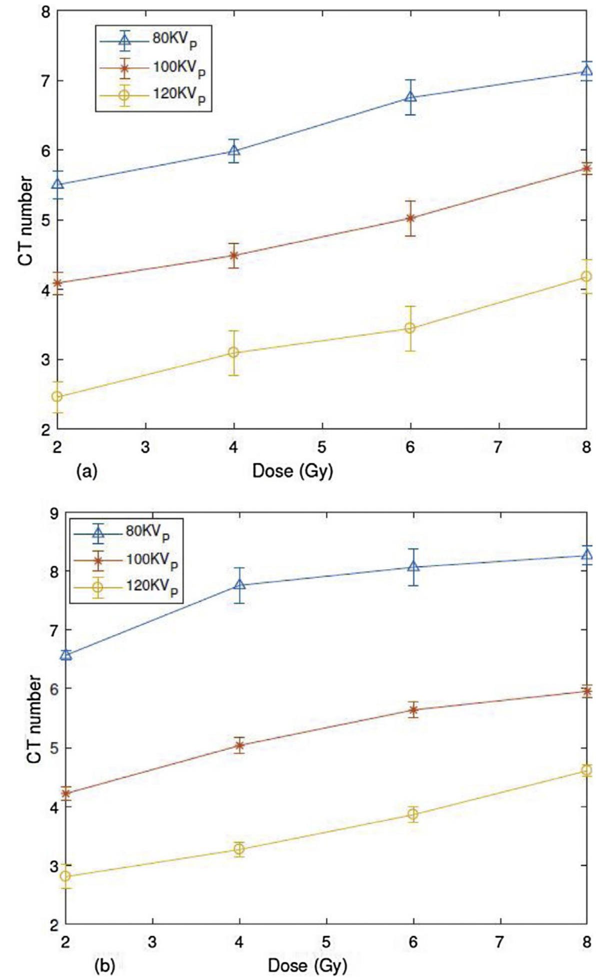

Fig. 2. The CT number variation for two slice thickness (a) 5 mm (b) 10 mm.

the monomer in a three-dimensional network and NIPAM has a monomer role that with BIS created a transverse connection and formed a polymer network. The THPC, as an antioxidant, creates a link with oxygen and prevents its presence in polymerization. Gel was transferred to the vials after the washing of vials with the de-ionized water. The gels in the vials were cooled at room temperature. The polymer gel dosimeters were manufactured inside a fume hood and under normal conditions. Quick gel temperature changes should be avoided when making the gel. The tubes were filled completely with gels and so the air inside the vials was completely evacuated to prevent excessive oxygen diffusion into the gel. The vials were kept in the refrigerator for 24 h at 4 °C.

3.2. Irradiation

Irradiation was implemented 24 h after gel formation. All gels were irradiated with 6 MV photons beam using the Elekta Cynergy Platform linear accelerator at a machine dose rate of 400 MU/min. This machine has been calibrated to deliver 1 cGy/MU at the standard condition as TRS-398 protocol. The vials of gel were placed in water and exposed to the radiation doses of 2, 4, 6, 8 Gy. One of the vials was left without irradiation for background subtraction. The gels were set up at SSD = 100 cm using a 25 cm × 25 cm field size, at the depth of 5 cm and the gantry angle of 90°. In the case of irradiation, the axis of the vials was perpendicular to the central axis of the beam. The vials were transferred to the refrigerator after radiation. Fig. 1, shows the irradiated samples of NIPAM gel vials.

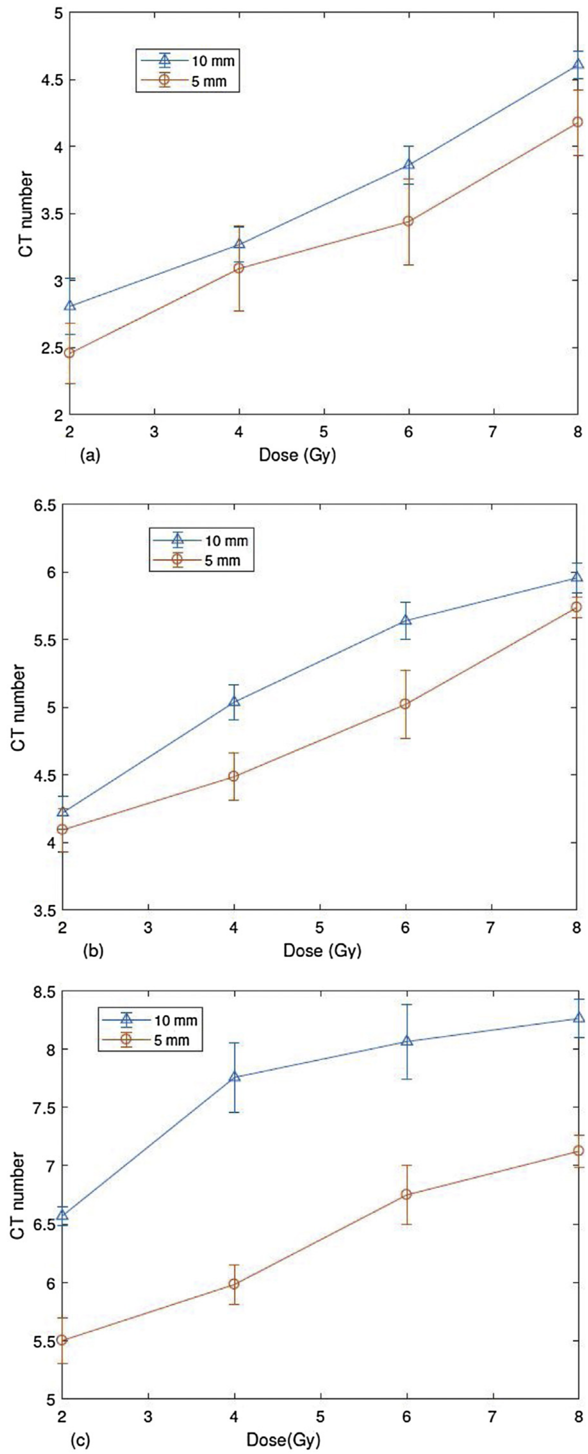

Fig. 3. The CT number variation with the same kVp for two slice thickness (a) 120 kVp, (b) 100 kVp and (c) 80 kVp.

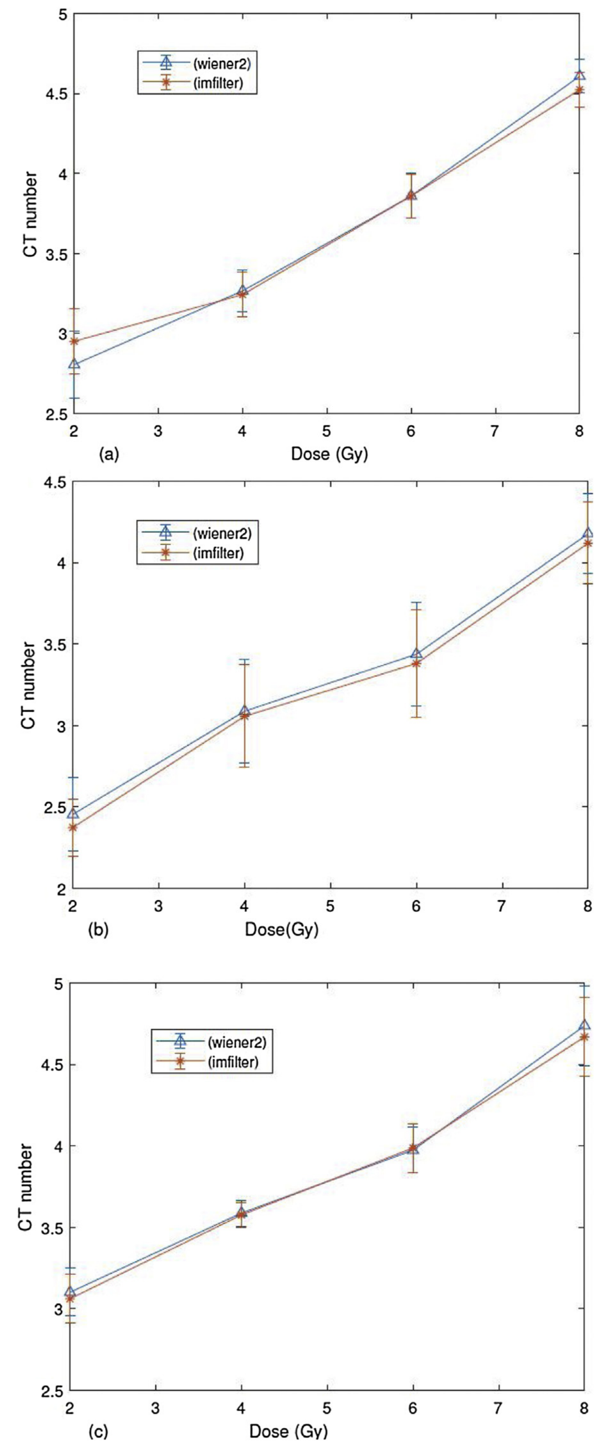

Fig. 4. The CT number variation with the different filtering recipe for 120 kVp (a) 10 mm, (b) 5 mm and (c) 2.5 mm.

3.3. Scanning

In this study, the X-ray CT was used for reading of irradiated NIPAM polymer gel vials. Illustration of gel vials 24 h after radiation was acquired with using a 16-slice CT scanner (GE Medical Systems, Milwaukee, USA). The field of view 20 cm × 20 cm and the 512 × 512 matrix size in the X-ray CT images were used. We computed the variation of CT number with dose for two slice thicknesses of 5, 10 mm and 80, 100 and 120 kVp and the calibration curves were plotted for these conditions. Also, the variation of CT number with dose was evaluated in the slice thickness of 2.5 mm and 120 kVp. The effects of two different filtering of Wiener2 and Imfilter on the calibration curve were evaluated.

4. Results and discussion

The variation of CT number with dose for two slice thicknesses 5 mm, 10 mm and 80, 100 and 120 kVp are shown in Fig. 2. It can be seen in this figure that there exists a correlation between the CT number and the absorbed dose for all the vials. The slope of diagram could be used to determine dose sensitivity of the studied polymer gel. The best sensitivity was obtained for 120 kVp and the slice thickness of 10 mm. In this study, the NIPAM polymer gel was scanned by the X-ray CT. The pixel intensity in the X-ray CT images was stated as the CT numbers, generally in Hounsfield units (H). A disadvantage of the X-ray CT gel dosimetry system is the delivery of radiation to the gel through the read out process; hence, we have to choose the best protocol to get the best response for the gel dosimeter. It is well known that the NIPAM polymer gel dosimeter is a suitable tool for 3D dose distribution to determine the CT number with dose. In Fig. 3(a) up to (c), the CT number with the respect to dose for different slice thicknesses (5 mm and 10 mm) is evaluated for the three different voltages: (a)120 kVp and (b) 100 kVp (c) 80 kVp. Those figures illustrate the effect of different kVp and slice thickness on the sensitivity of gel. It is clear that the sensitivity was increased with the increase of slice thickness and kVp. By increasing the slice thickness at the specified kVp, more sensitivity can be predicted. The dose sensitivity of 0.29 ± 0.01 was calculated for the NIPAM polymer gel. The results are in good agreement with the Koeva studies.[23] The standard deviation CT number was measured in the center of image and for the slice thickness 10 mm smaller than 5 mm. In this work our focus was on the filtering space by using the MATLAB software. The recipe of different filtering is exerted in Fig. 4(a) up to (c) that show the effect of two recipes of different filtering of Wiener2 and Imfilter on the sensitivity of NIPAM gel in the different slice thicknesses. If the calculations are made on the pixels in a linear neighborhood, the operation is called a linear spatial filtering. The term of space, directly refers to the methods for manipulating the image pixels. In the linear filtering method, the filter response is equal to the sum of the product of the coefficients of pixels adjacent to the area covered by the mask. The wiener2 function is applied as a type of a linear filter for any images. The wiener2 function organizes all the preliminary calculations and implements any input images. Image filtering methods have been suggested for the image enhancement in the X-ray CT imaging of polymer gel dosimeter and also necessary for reducing noise in the gel images. There is a significant difference between these two filterings.

5. Conclusion

In this study, the dependence of CT number on dose was investigated in the NIPAM polymer gel dosimeter by using X-ray CT. Regarding the need of improving the sensitivity of this gel for use in treatment, we could gain the best sensitivity in 120 kVP and slice thickness 10 mm. This means that, although the spatial resolution will decrease, the most sensitivity of NIPAM polymer gel dosimeter will be gained in the biggest thickness. Therefore, this sickness could be used for measurements of dosimetry parameters such as output factors. The changing of monomer percentage used in the gel and the formalism of gel is proposed to further improve sensitivity of NIPAM polymer gel in the future works.

Financial disclosure

There is no financial disclosure to statements.

Conflict of interest

None declared.

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References

1. Jirasek A, Carrick J, Hilts M. An X-ray CT polymer gel dosimetry prototype I: Remnant artefact removal. *Phys Med Biol*. 2012;57:313753.
2. Kakakhel MB, Kairn T, Kenny J, Trapp JV. Improved image quality for X-ray CT imaging of gel dosimeters. *Med Phys*. 2011;38:5130–5135.
3. Kakakhel MB, Jirasek A, Johnston H, Kairn T, Trapp JV. Improving the quality of reconstructed X-ray CT images of polymer gel dosimeters: Zero-scan coupled with adaptive mean filtering. *Australas Phys Eng Sci Med*. 2017;40:159–165.
4. Parwaie W, Yarahmadi M, Nedaie HA. Evaluation of MRI-based MAGIC polymer gel dosimeter in small photon fields. *Int J Radiat Res*. 2016;14:57–63.
5. Yarahmadi M, Wegener S, Sauer OA. Energy and field size dependence of a silicon diode designed for small-field dosimetry. *Med Phys*. 2017;44:1959–1964.
6. Verona C, Magrin G, Solevi P, Bandorf M, Marinelli M, Stock M, et al. Toward the use of single crystal diamond based detector for ion-beam therapy micro dosimetry. *Radiat Meas*. 2018;110:25–31.
7. Dybek M, Kozowska B. Evaluation of the applicability of MOSFET detectors in radiotherapy. *Radiat Meas*. 2014;71:412–415.
8. Haghparast A, Amiri F, Yarahmadi M, Rezaei M. The peripheral dose outside the applicator in electron beams of an Elekta linear accelerator. *Australas Phys Eng Sci Med*. 2018;41:647655.
9. Guillerminet C, Gschwind R, Makovicka L, Spevacek V, Soukoup M, Novotny J. The use of polyvinyl chloride films dyed with methyl red in radiation dosimetry. *Radiat Meas*. 2005;39:39–42.
10. Baldock C, De Deene Y, Doran S, Ibbott G, Jirasek A, Lepage M, et al. Polymer gel dosimetry. *Phys Med Biol*. 2010;55:63.
11. Jirasek A, Hilts M. An overview of polymer gel dosimetry using x-ray CT. *J Phys Conf Ser*. 2009;164:246–256.
12. Schriner LJ, Olding T, Mcauley KB. Polymer gel dosimetry. *J Phys*. 2010;250:012014.
13. Maryanski MJ, Schulz RJ, Ibbott GS, Gatenby JC, Xie J, Horton D. Magnetic resonance imaging of radiation dose distributions using a polymer-gel dosimeter. *Phys Med Biol*. 1994;39:1437–1455.
14. Oldham M. Optical-CT scanning of polymer gels. *J Phys Conf Ser*. 2004;3:122–135.
15. Hilts M, Audet C, Duzenli C, Jirasek A. Polymer gel dosimetry using X-ray computed tomography: A feasibility study. *Phys Med Biol*. 2000;45:2559–2571.
16. Trapp JV, Back SAJ, Lepage M, Michael G, Baldock C. An experimental study of the dose response of polymer gel dosimeters imaged with x-ray computed tomography. *Phys Med Biol*. 2001;46:2939–2951.
17. Rintoul L, Lepage M, Baldock. Radiation dose distribution in polymer gels by Raman spectroscopy. *Appl Spectrosc*. 2003;57:51–57.
18. Mather ML, De Deene Y, Whittaker AK. Investigation of ultrasonic properties of PAG and MAGIC polymer gel dosimeters. *Phys Med Biol*. 2002;47:4397–4410.
19. Hilts M. X-ray computed tomography imaging of polymer gel. *J Phys Conf Ser*. 2006;56:95–107.
20. Ghavami SM, Mesbahi A, Pesianian I, Shafaee A, Aliparasti MR. Normoxic polymer gel dosimetry using less toxic monomer of N-isopropyl acrylamide and X-ray computed tomography for radiation therapy applications. *Rep Pract Oncol Radiother*. 2010;15:172–175.
21. Jirasek A, Johnston H, Hilts M. Dose rate properties of NIPAM based X-ray CT polymer dosimeters. *Phys Med Biol*. 2015;60:4399.
22. Senden RJ, De Jean P, McAuley KB, Schreiner LJ. Polymer gel dosimeters with reduced toxicity: A preliminary investigation of the NMR and optical dose-response using different monomers. *Phys Med Biol*. 2006;51(14):3301–3314.
23. Koeva VI, Olding T, Jirasek A, Schreiner LJ, McAuley KB. Preliminary investigation of the NMR, optical and X-ray CT dose-response of polymer gel dosimeters incorporating cosolvents to improve dose sensitivity. *Phys Med Biol*. 2009;54:2779–2790.