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Research Article

Implementation of MRI normoxic polymer gel dosimetry in external beam radiotherapy

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Abstract

Background. The purpose of this work was to study the ability of MRI normoxic polymer gel dosimetry system

Methods. To accomplish of this study, 2 liter of the normoxic MAGAT polymer gel was composed. A Perspex phantom and five calibration test tubes were also prepared. The test tubes were filled in with the gel. This phantom was then CT scanned and dose plan was product. The gel phantom and the test tubes were then irradiated .Prior to irradiation, MR scans were performed to measure the background value of R_2 of the gel. Immediately after irradiation new images of the gel phantom (and calibration test tubes) were obtained using the MR scanner. Finally, from the MRI images in MATLAB environment R_2 maps were calculated.

Results. In this study, and in point center (PC) the difference between the treatment planning system TPS and gel dosimeter data was 1.15% (SD = 1.8%). Dose sensitivity and dose resolution of MAGAT gel dosimeter were 5.033 $S^{-1}Gy^{-1}$ (R^2 =0.9953), 1.974 Gy respectively.

Conclusion. In this work, the TPS calculations compared with polymer gel dosimeter measurements and found the dose distributions calculated with the TPS is in very good agreement with the Polymer gels measuring.

Keywords: gel dosimetry; normoxic; MAGAT; calibration; radiotherapy

1. Introduction

In radiotherapy there is a great need for accurate determination of the adsorbed dose of tumor tissue as well as to healthy organs at risk. The absorbed dose delivered to the planning target volume (PTV) should be ±%5 of the stated dose (Other authors suggest ±%3) [1]. To accomplish this goal, most treatments are executed according to a calculated plan. In clinical cases verification of the calculated dose plan by measurements is often complicated .This is especially true if the treatment comprises server al beams of different field and radiation qualities and if the beams impinge on an irregularly shaped body section containing various kinds of tissues or cavities. One method to verify clinical treatments is to carry out measurements using thermoluminescence (TL) dosimeters in patient-like phantoms [2]. This method is limited with respect to the absorbed dose in a limited number of points.

Furthermore, the detectors may disturb the radiation beam or their signal be dependent on the radiation qualities used as well as the direction of the incident radiation .These are problems which TL dosimeters share with most other dosimetry systems such as diodes and ionization chambers. Most conventional dosimetry techniques that mentioned above are incapable of 3D measurements. Polymer gel dosimeters are able to measure dose distributions for several beams and different beam qualities (e.g., photons and electrons) [3]. The purpose of the present study was to study the ability of MRI normoxic MAGAT polymer gel dosimetry system as a tool to verify the calculated dose distributions in clinical radiotherapy (Prostate cancer).

2. Material and methods

For verification of absorbed dose distribution using the MAGAT gel dosimeter initially, a cylindrical Perspex phantom simulating a patient and a number of calibration test tubes were designed and composed (Fig.1). 2 liter of the normoxic MAGAT polymer gel under normal atmospheric conditions was prepared according to the reference method

[4]. Five calibration test tubes and the Perspex phantom were filled in with the prepared gel. The phantom was then CT scanned and a dose plan was generated using the obtained CT data (Fig. 2). Prior to the irradiation, MRI scans of the phantom was taken to measure the background value of R_2 (Fig. 3 and Table 1, 2). The gel phantom was irradiated according to four field (Box) technique protocol. The calibration test tubes were also irradiated by a cobalt-60 tele therapy unit (Fig. 4,).Immediately after the irradiation, new images of the phantom and the calibration test tubes were acquired using the MRI scanner. Finally, using the MRI images in MATLAB environment R_2 maps were calculated.

2-1.The Phantom, test tube and gel preparation

In this study, a special sylandric Perspex phantom was designed to investigate dose distribution in external beam radiotherapy of urinary bladder. Perspex was chosen because it is relatively soft tissue equivalent and cheap, easily machined and useful for constructing phantoms of varying shapes. Thickness the walls of phantom was 1cm Perspex and the dimensions were 15 cm in diameter, 15 cm in height and 1200ml capacity. This phantom is composed of 3 separate units. The central one contains gel dosimeter (1200ml) and the other two contain the pure water (19 x 25 cm, and 3600ml capacity). For calibration purpose, relatively small Pyrex tubes were designed with 2mm wall thickness, 1.5mm diameter, 8cm height and 15.5ml capacity (Fig. 1).

"MAGIC" which stands for "Meth acrylic and Ascorbic acid in Gelatin Initiated by Copper", was the first normoxic polymer gel proposed by Fong et al. in 2001[4]." MAGAT" polymer gel is one of the most sensitive radiation of the normoxic gels, that had been used in this study. The fabricating of the new gel followed the same manner as reported for MAGIC .For fabricating of 2 liter of this gel we used; 160 gr gelatin (type A, 3oo bloom), .662 gr THPC agent, 100 gr meth acrylic acid (MAA) and 1740 ml HPLC water.

2-2. Calibration and irradiation

In this study a standard calibration multi-tube with five test tubes were employed. A tele-therapy Cobalt-60 machine (Theratron 780- AECL) was used to irradiate the test tubes laterally when they were horizontally fixed inside a water tank at the depth of 5cm with a source-to-surface distance (SSD) of 80 cm (Fig. 4). One tube was left Un-irradiated while the others were irradiated to doses of 2,4,6,8 Gy. Front and back surfaces of the tubes were marked by adhesive stickers and the test tubes were irradiated with their front side facing up to the beam. This marking was later used for positioning the imaging slice at the middle of the test tubes between the front and back surfaces where the gel was exactly at the depth of 5 cm during irradiation. The gel phantom was irradiated according to four field (Box) technique protocol that come followed in table 1.

Fig 1. *Phantom and calibration test tubes to be used (in this study)*

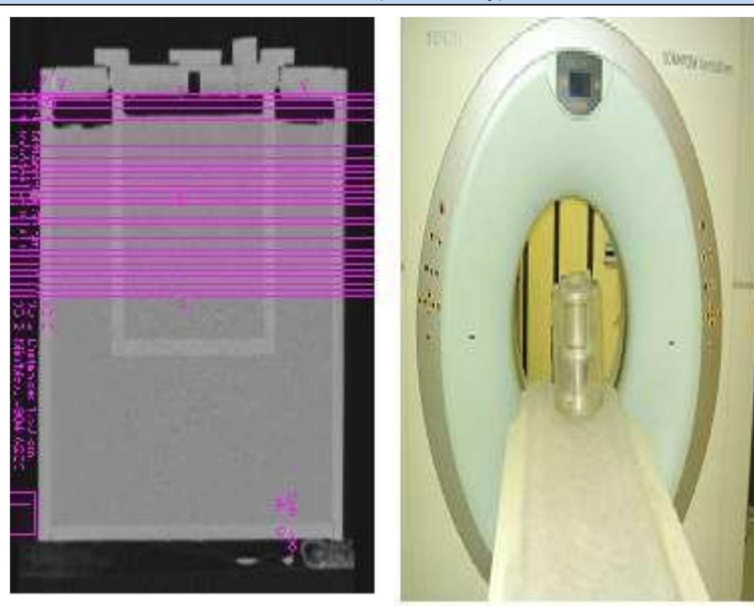

Fig. 2. *CT scanner system and DICOM image of phantom*

 

Fig.3 *MRI scanner system used in this study*

Fig.4 *Calibration set up under the tele therapy Cobalt unit in multi – tube method*

Treatment time (Min)	(SSD) (cm)	field size (cm)	Prescribed dose from one field (cGy)	Technique
1.8	80	10 x 10	50	Four field (Box)

Table 1. *Irradiation parameters for prostate cancer treatment (Box technique)*

2-3. CT and MRI Imaging, data post-processing

CT scanning of the phantom was performed by a Siemens Somatom Plus-s, 64 slice, and rotate-rotate machine of the third generation. MRI scans of the phantom and the calibration test tubes were also taken to extract the spin- spin relaxation rates and R_2 maps (Table 2). Images were obtained in a plane in the middle and across the longitudinal cross section of the Phantom and test tubes. 16 MRI images for the phantom and 32 images for the test tubes were obtained. MRI images were transferred in DICOM format to a personal computer for further image processing. Image averaging and background subtraction were performed using the special software (is named R_2 calc), that is performed in MATLAB™ environment. Also an Adaptive and a Median filter with different pixel size masks were also applied on the final polymer gel dosimeters images.

Scanner parameters	Scanner data
Scanner type	Siemens Avanto (Germany)
Field strength	1.5 Tesla
RF frequency	65 MHz
Coil used	Quadrature head coil
Pulse sequence	Multi-spin echo (CPMG)
TR (ms)	3000
TE (ms)	22-704 , TE_n= 32(TEi =22)
FOV Read (mm)	260 , 230
Matrix size	512×512
Slice thickness (mm)	

Table 2. *MRI Scanner Parameters employed in this study*

3. Results

3-1. Calibration results

The calibration results is followed in table 3, 4 and Fig .6. Based on these results the dose sensitivity of MAGAT gel dosimeter was 5.033 $S^{-1}Gy^{-1}$ (R Square, (R^2), =0.9953). Dose linearity and dose resolution of this normoxic gel were determined also, and were 0 – 8 Gy , 1.974 Gy respectively.

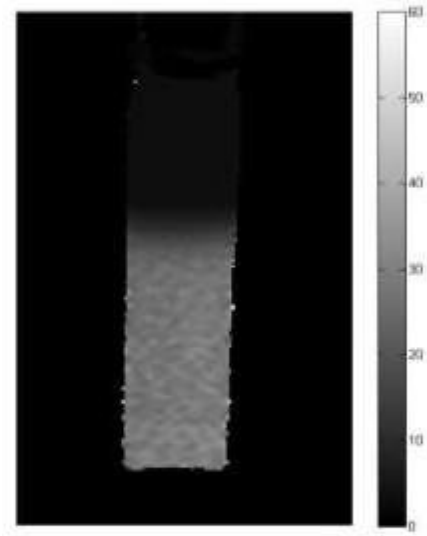

Fig.5 *MRI slices of calibration test tubes*

Number of test tubes	Dose (Gy) at the central axis of the test tube	Irradiation time (min)	R_2 (at the central axis of the test tubes and sagital plan) (1/s)	SD (σ_{cal})
Blank	0	0	5.35	0.34
2	2	3.05	17.36	0.64
3	4	6.11	28.12	1.66
4	6	9.16	36.03	3.53
5	8	12.22	46.35	11.90

Table 3 *Results of multi-tube calibration (in this study)*

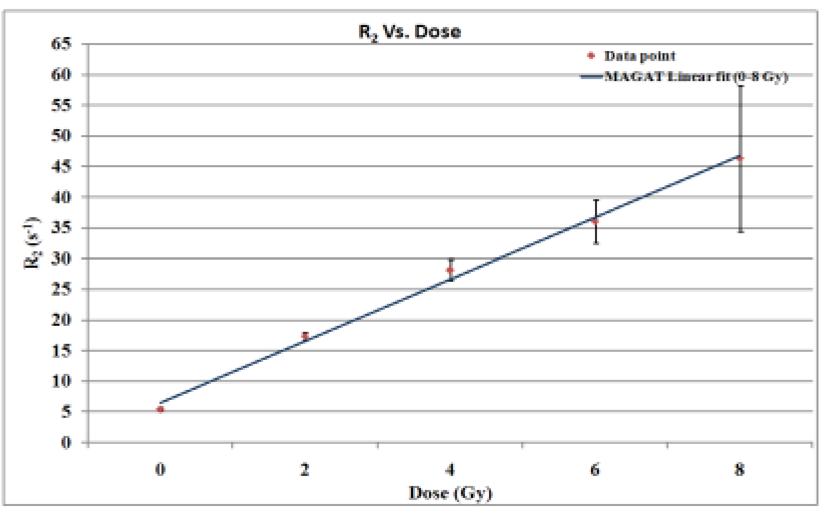

Fig.6 *Dose response curve of MAGAT gel dosimeter was built in this study*

Comments	Special indexes	Dose-response equilibrium	features / Linearity (Gy)
Coefficients (with 95% confidence bounds(	SSE*=4.7886 R Square =0.9953	Linear fitted model Polynomial: $R_2(D) = P1*D + P2$ P1 =5.033 (4.397, 5.669) P2 =6.509 (3.395, 9.624)	0-8

* Sum Squared Error

Table 4 *Property of MAGAT gel in multi-tube calibration (in this study)*

3-2. Radiotherapy procedures results

Four field technique normally applied for treatment of cancer of urinary bladder was implemented to a gel dosimetry phantom. Gel dosimetry and treatment planning system (ALFARD, Version 4.46.7 SPL WP) were employed to obtain the absorbed dose distribution. Homogenous dose distributions were produced by both techniques. R_2 maps and dose contours of the MAGAT gel phantom were obtained in different views after using a adaptive and median filter (5x5, 10x10 and 2x10 masks) (Fig. 7, 8, 9, 10, 12) . R_2 profile of MAGAT gel phantom in different views also determined (Fig. 11,13).Dose Volume Histograms (DVHs) and the normalized isodose contours for gel and TPS (ALFARD) system obtained and compromised (Fig. 16).

ICRU (42) guidelines and Van Dyk et al. researches were implemented to comparing and evaluating these dose distributions [6, 7]. The ICRU (42) has recommended that the computed dose should deviate from measured dose by less than 2% [6]. In this study and in the region of interest (at the central slice of the phantom, point center) the difference in the dose obtained by gel dosimetry and TPS is 1.15% (SD = 1.8%), and in penumbra region was 2 - 4%.

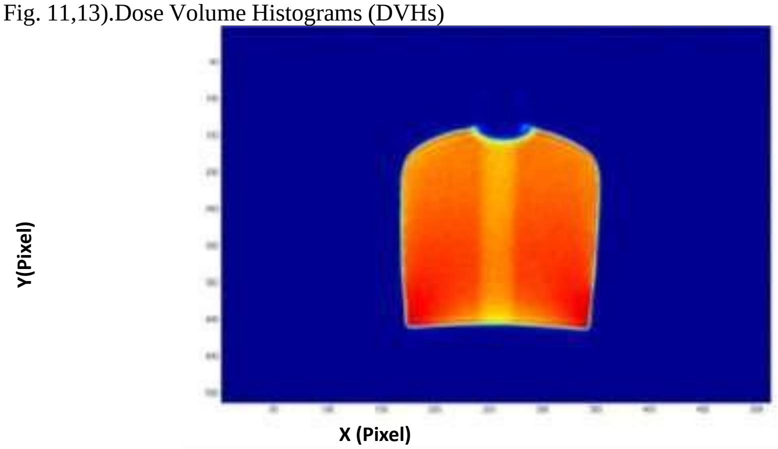

Fig.7 *The coronal view of the pre-irradiated gel phantom*

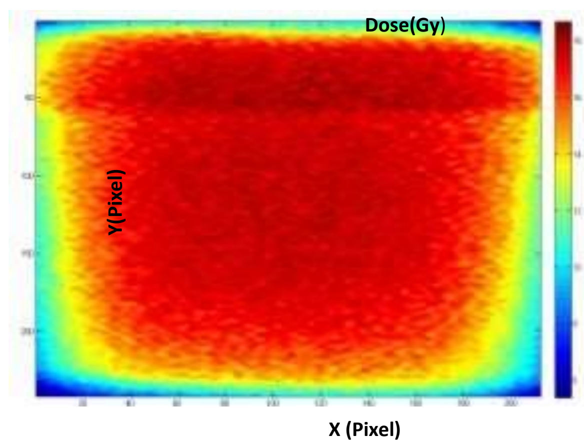

Fig.8 *The coronal view of the post-irradiated MAGAT gel phantom (Box technique)*

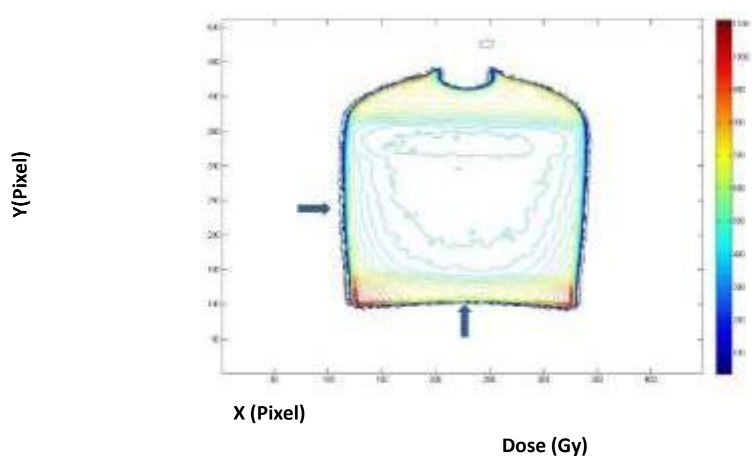

Fig.9 *R2 contour of MAGAT gel phantom in coronal view after Using an adaptive filter (10 x 10 mask) (Box technique)*

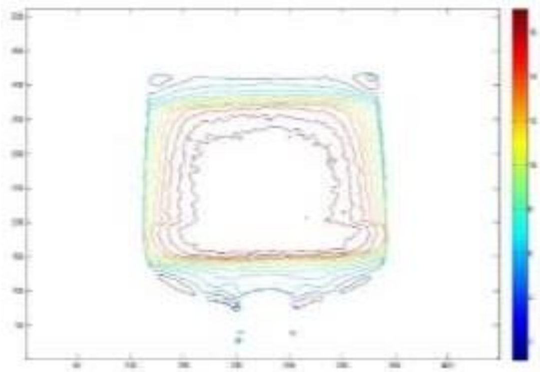

Fig.10 *Dose contour of MAGAT gel phantom in coronal view after Using a adaptive filter (10 x 10 mask) (Box technique)*

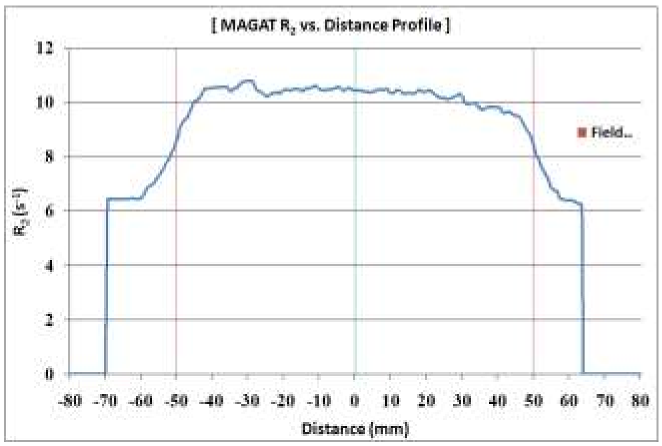

Fig.11 *R2 profile of MAGT gel phantom in coronal view (Box technique)*

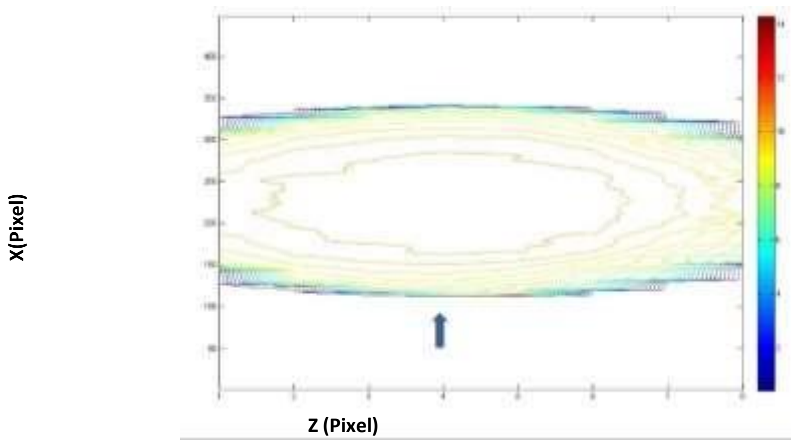

Fig.12 *R2 contour of MAGAT gel phantom in Trans axial view after Using a adaptive filter (2*10 mask) (Box technique)*

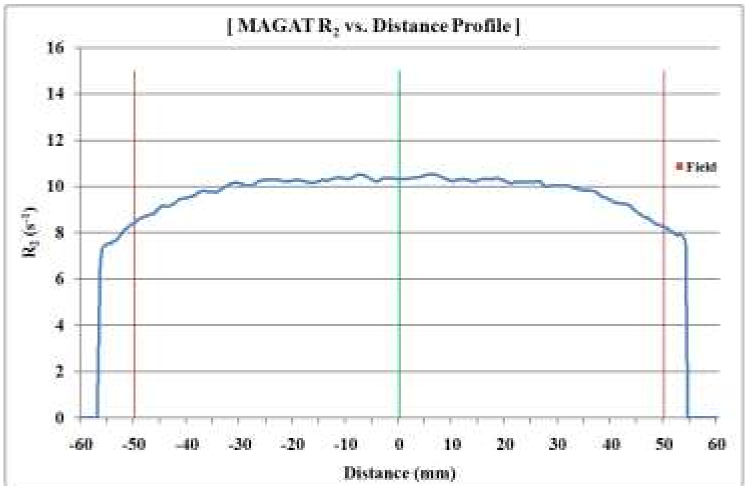

Fig.13 *R2 profile of MAGAT gel phantom in Trans axial view (Box technique)*

4. Discussion

In this study dose distribution of a clinical treatment procedure produced by MRI normoxic polymer gel dosimetry and TPS were investigated. This was accomplished by pixel-by-pixel, isodose and dose volume histogram (DVH) comparison. Based on results, dose-integrating capacity of the gel dosimeter was demonstrated. A good agreement was also found between the data obtained by the two methods employed. The TPS calculated data were in very good agreement with the distribution measured by polymer gel dosimeter. How ere, in a beam abutment region (for the penumbra of the lateral scatter contribution), larger dose difference was found (DD = 2- 4 %). The new polymer gel that was fabricated in this study, was also found to have a higher dose sensitivity compared to other normoxic gels.

5. Conclusion

Polymer gel dosimetry has been developed into a totally non-invasive and non-destructive dosimetry method, since the dosimeter gel phantom itself forms the detector. The gel dosimeter is capable of measuring dose distributions from several beams and beams of different radiation qualities (e.g. photons and electrons) in all parts of the dosimeter volume[7]. These properties imply that the gel dosimeter may be used to verify a dose plan. The purpose of this work was to study whether computerized planned clinical treatments could be verified using the gel dosimeter and to examine possible explanations to deviations found between the calculated and measured dose distribution. Based on the results of this study, the gel dosimetry method was proven to be a useful tool for radiation treatment planning verification.

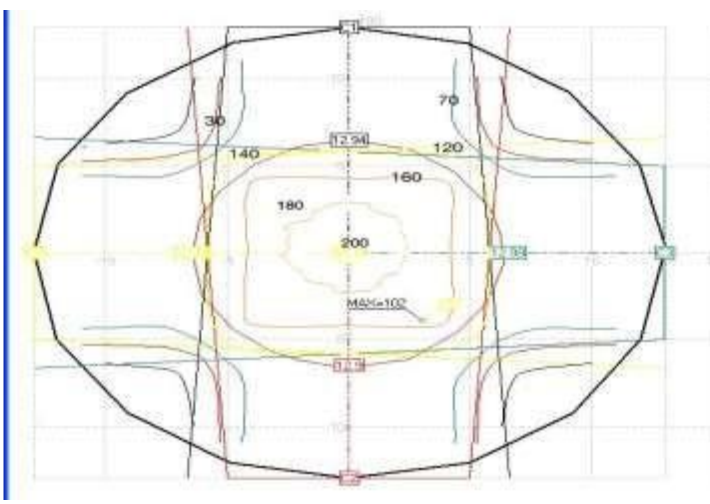

Fig.14 *Isodose curves by ALFARD treatment planning system (Box technique)*

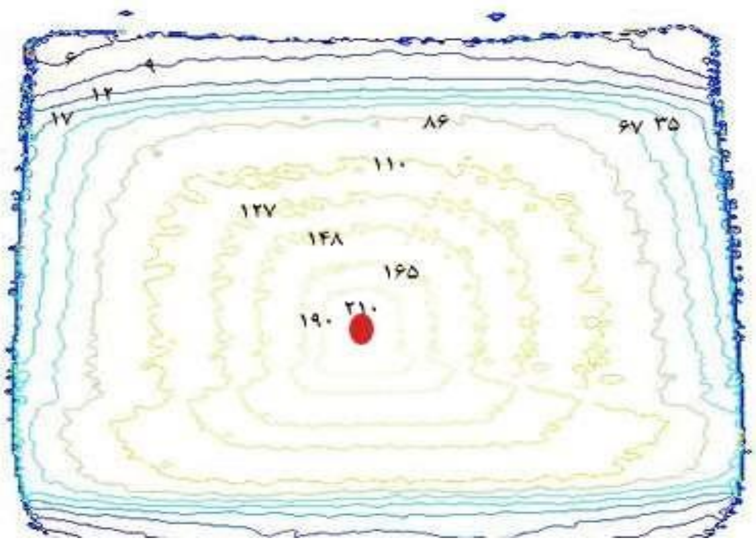

Fig.15 *The normalized isodose contours by MAGAT gel Dosimetry system in this study (Box technique)*

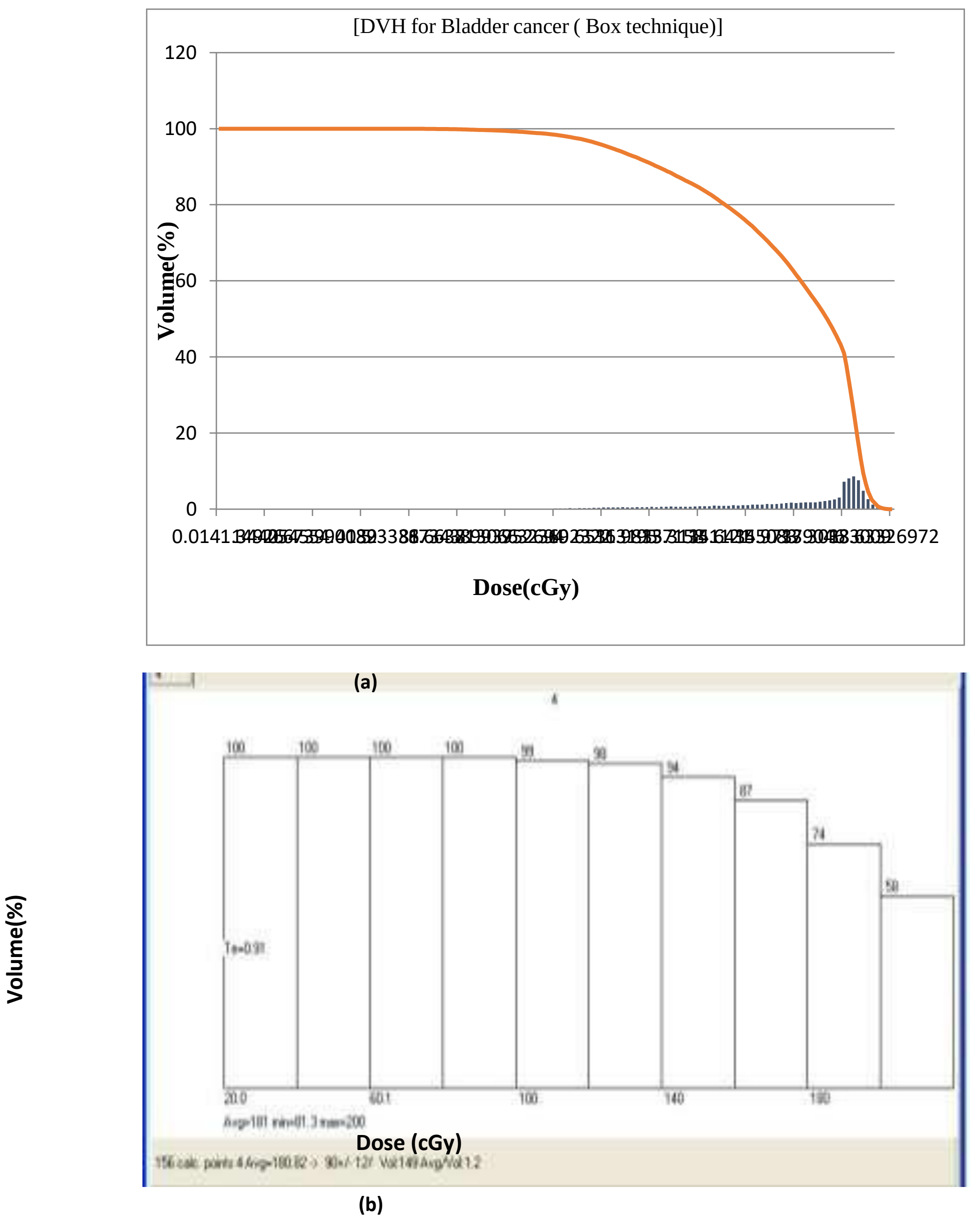

Fig.16 *Dose Volume Histogram (DVH) of MAGAT gel phantom and TPS in Box technique (a: gel dosimeter and b: ALFARD TPS)*

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