# Preliminary Investigations of the Dosimetric Properties of a Normoxic Polymethacrylic Acid Gel Dosimeter Using a Respiration-Motion Simulator

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Dose distribution throughout the clinical organ range of motion was analyzed using a respiratory-motion simulator that was equipped with a polymer gel dosimeter and EBT2 film. The normoxic polymer gel dosimeter was synthesized from gelatin, MAA, HQ, THPC and HPLC. The gel dosimeter and EBT2 film were irradiated with Co-60 gamma rays that were moved along the x-axis and y-axis in ±1.5 cm steps at five-second intervals. The field size was 5×5 $cm^2$. The SSD was 80 cm and set to 10 Gy at a depth of 2 cm. The PDD at a depth of 50 mm was 75.2% in the ion chamber, 82.3% in the static state and 86.1% in the dynamic state in the gel dosimeter. The penumbra for the dynamic state target, which was measured using the gel dosimeter, averaged 10.89 mm, this is a 40.5% increase over the penumbra of the static state target of 7.74 mm. In addition, when measuring with gel dosimetry, the value for the penumbra is 36.6% smaller in the static state and 29.4% smaller in the dynamic state compared to measuring with film. The aim of this study was to investigate the dosimetric properties of a normoxic polymethacrylic acid gel dosimeter in static and dynamic states and to evaluate the potentiality as a relative dosimeter for dynamic therapeutic radiation.

**Key Words**: Polymer gel dosimeter, Film, Moving target, Dose response

## INTRODUCTION

Ideally, radiation therapy accurately delivers radiation to the treatment area, also the planned radiation dose should equal the delivered radiation dose. However, in cases of internal organs and tumors that move during breathing, it is difficult to deliver an accurate dose to the treatment area. Thus, in 3-dimensional conformal radiation therapy, it is important to confirm the dose distribution.

Two dimensional dosimeters, such as a film, are mainly used for dosimetry, nevertheless there are some limitations in measuring the spatial dose distribution. The polymer gel dosimeter as a three dimensional dosimeter is currently being carried out to overcome such limitations.

Most studies that have attempted to verify that a radiation dose was accurately delivered to moving organs and tumors during respiratory movement used films that measure the 2-dimensional dose distribution. Thus, the results of these studies depended on whether the apparatus reduced the internal organ motion.[1] They analyzed the dose distribution after setting the time gating threshold (TGT) according to the organ motion so that it was in tune with the breathing cycle,[2] and measured the dose distribution depended on whether a multileaf collimator (MLC)[3] and a moving phantom were used.

Kanagaki et al. reported the differences between the radiation isodose distribution measured under static conditions as a control using a computer controlled stepping motor and films.[4] S. Ceberg et al. investigated the feasibility of using a 3D gel dosimeter for dose verification of dynamic radiotherapy.[5] Kim

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et al. observed the distortion of dose profile to consider the respiratory motion effects using a Gafchromic film and a polyethylene cubic phantom.[6)]

Suh et al. studied clinical acceptable differences between the dose distributions from a static target and a moving target with a moving phantom and film dosimetry.[7)]

In this work we fabricated a polymer gel dosimeter that uses polymethacrylic acid as the monomer under normoxic conditions. The gel dosimeter and film were installed in a respiratory-motion simulator, and the dose distributions in the static and dynamic states were measured. After irradiation with Co-60 gamma rays, an image was obtained using MRI, and the percent depth dose and penumbra effect were analyzed.

## MATERIALS AND METHODS

### 1. Gel dosimeter

The polymer gel that was used in the dosimeter was fabricated from gelatin (300 bloom, Sigma-Aldrich, St. Louis, MO, USA), MAA (methacrylic acid, Sigma-Aldrich), THPC (tetrakis hydroxymethyl phosphonium, Sigma-Aldrich), HQ (hydroquinone, Sigma-Aldrich), and high-purity distilled water (HPLC) in normoxic conditions.[8)] For polymer gel synthesis, HPLC and gelatin were used at 86% and 6% of the total amount, respectively. These were placed in a reaction flask until the gelatin became completely swollen. The flask was then stirred until the contents liquefied while being heated slowly to 50°C.

After the gelatin was fully dissolved, the temperature was reduced to 43°C while stirring. Next, 8% MAA, 0.05 mM HQ and 10 mM THPC were added, in that order, with stirring for 10 minutes between each addition. THPC, which is an antioxidant, was added last to prevent the loss of antioxidant properties due to the introduction of oxygen during the gel synthesis process (Fig. 1). After the synthesis process was completed, the polymer gel solution was placed in an acryl phantom, left at room temperature for approximately one hour and then stored in a refrigerator.[9)] The interior dimensions of the acryl phantom that contained the gel dosimeter were $15\times15\times10$ cm$^3$, and all the acryl planes included a cover that was 8 mm thick.

### 2. Respiratory-motion simulator

A respiratory-motion simulator was used to simulate the internal organ motions that result from respiration (Fig. 2). This system consisted of a moving phantom, in which the dosimeter could be placed, and a controller. The respiratory-motion simulator was constructed from aluminum alloy and the maximum movement distance was 10 cm, the motions of the simulator in the x- and y-direction are simultaneous. The movement working resolution was designed to be 20 $\mu$m. The maximum response speed of the multileaf collimator target-tracking system was 100 mm/s. In the actual experiment, all of the new location values were transmitted every 50 ms and were synchronized with the other equipment.[3)]

### 3. Irradiation

For the irradiation, a Co-60 teletherapy unit (Theratron-780, AECL, Ottawa, Canada) was used at a dose rate of 117.66 cGy/min. Using the respiratory-motion simulator, the polymer gel dosimeter and Gafchromic EBT2 film (ISP, USA) were irradiated in static and dynamic states with 10 Gy each (Fig. 2). The source-to-surface distance (SSD) was 80 cm, and the field size was $5\times5$ cm$^2$. The respiratory-motion simulator moved ±1.5 cm in the x-axis and y-axis, which is within the range of clinical organ motions, in a respiratory-like cycle and was irra-

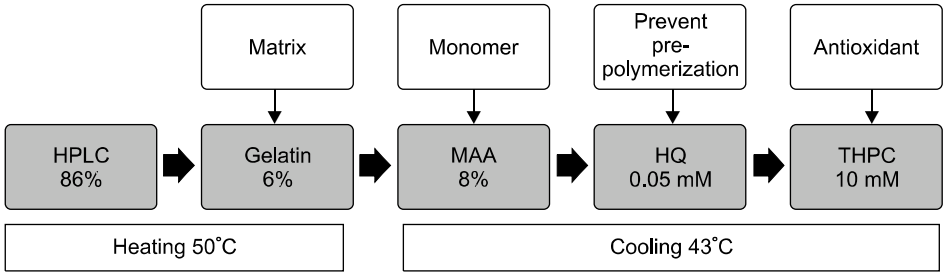


**Fig. 1.** Fabrication procedure of the polymer gel in normoxic conditions.

diated at five-second intervals (Table 1).

The gel dosimeter was irradiated at a depth of 2 cm from the acryl phantom surface, while the film was irradiated with a 2 cm-thick tissue-equivalent solid phantom on the top.

## 4. MRI measurement

To analyze the irradiated gel dosimeter, an MRI system (MAGNETOM Trio a Tim, 3T, Siemens, Germany) was used to obtain images.

As temperature can affect image evaluation, the irradiated polymer gel dosimeter was placed in the MRI room for twenty-four hours prior to images been taken in order to reach a temperature equilibrium.[10,11] Images were obtained at a depth of 2 cm from the gel dosimeter surface using the following scanning conditions: TR (time of repetition) of 3,000 ms, TE (time of echo) of 20～140 ms and interval of 20 ms, slice thickness of 3 mm, field of view of 260×260 $mm^2$, bandwidth of 125 Hz. In addition, a head coil was used.[9] As the acryl phantom is not visible to the MRI system, two cross sections were obtained for the left and right directions at 2 mm intervals and at a location 5 cm below the gel surface, yielding a total of five cross-sectional images. Image J (1.43 u, National Institutes of Health, USA), Origin™ 8 (OriginLab Corp., MA, USA), and Matlab™ (The Math Works, Inc, USA) were used to analyze the obtained gel dosimeter images. For the EBT2 film, PTW-VeriSoft software (PTW, Freiburg, Germany) was used for background subtractions, and the dose distribution and profile were obtained after normalization.

The percent depth dose (PDD) was compared for the ion chamber, static state and dynamic state of the polymer gel dosimeter. The polymer gel dosimeter presented the PDD with respect to the central axis for the image obtained using MRI.

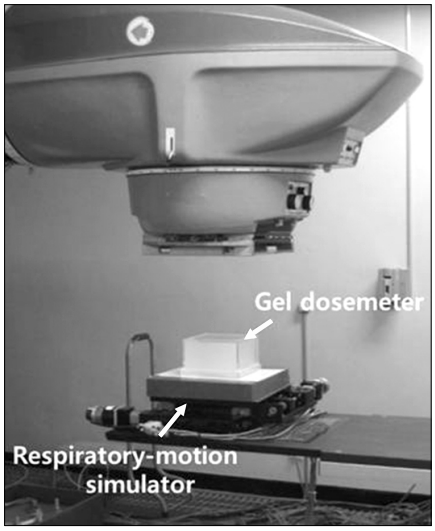


**Fig. 2.** Experimental setup of the Co-60 teletherapy unit with a gel dosimeter and a respiratory-motion simulator for static and dynamic dosimetry.

**Table 1.** Operation parameters that were used to evaluate the effectiveness of the delivered dose using a polymer gel dosimeter and Gafchromic EBT2 film.

| Operation parameters | Specifications |
|---|---|
| Dosimetric tool | Polymer Gel and Gafchromic EBT2 film |
| Radiation type | Co-60 gamma rays |
| Delivered dose | 10 Gy |
| Dose rate | 117.66 cGy |
| Field size | 5×5 $cm^2$ |
| SSD | 80 cm |
| Displacement of target | ±1.5 cm for the x-axis and y-axis |

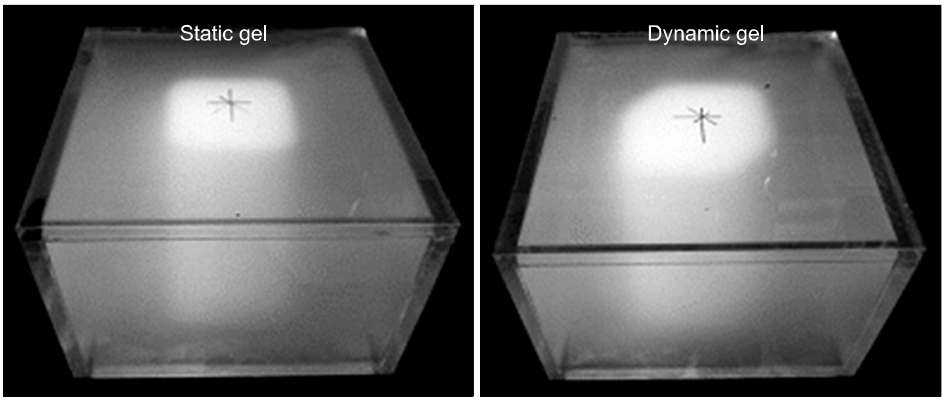


**Fig. 3.** Polymerization after irradiating the polymer gel dosimeter in static and dynamic states.

The PDD was presented in a range between 10 mm and 60 mm.

The profile and penumbra were obtained for images using the polymer gel dosimeter and EBT2 film at a depth of 2 cm by using MRI and a film scanner. The obtained images were analyzed in static and dynamic states along the x-axis. Flatness and symmetry were measured within a region bounded by a field contour of 80% of the maximum field size at a 2 cm depth in the polymer gel phantom.[12] The penumbra area is the edge of the radiation beam, over which the dose rate changes rapidly as a function of distance from the beam axis. The penumbra width was measured as the lateral distance between the 20% and 80% isodose curves at a specified depth.

Field flatness for photon beams has been traditionally defined as the variation of dose relative to the central axis over the central 80% of the field size. The flatness is given by the following equation:

$$flatness(\%) = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \times 100$$

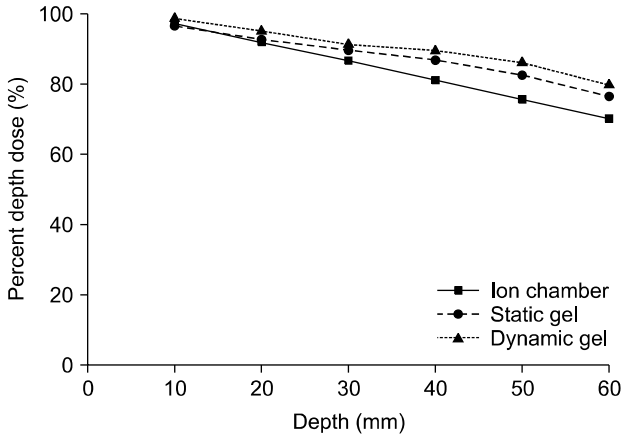


**Fig. 4.** PDD comparison between the polymer gels using Co-60.

## RESULTS AND DISCUSSION

Fig. 3 shows the gel dosimeter results after irradiation of the static and dynamic state targets. The polymerization that was caused by the irradiation of the transparent gel dosimeter in the acryl container was visible to the naked eye.

The measurements of the PDD using the polymer gel dosimeter and the ionization chamber are compared as a function of the phantom depth in Fig. 4.

The PDD at a depth of 50 mm was 75.2% in the ion chamber, 82.3% in the static state and 86.1% in the dynamic state in the gel dosimeter. Compared to the PDD in the ion chamber, the PDDs of the static and the dynamic states were overestimated by 7.1% and 10.9%, respectively. The dmax region

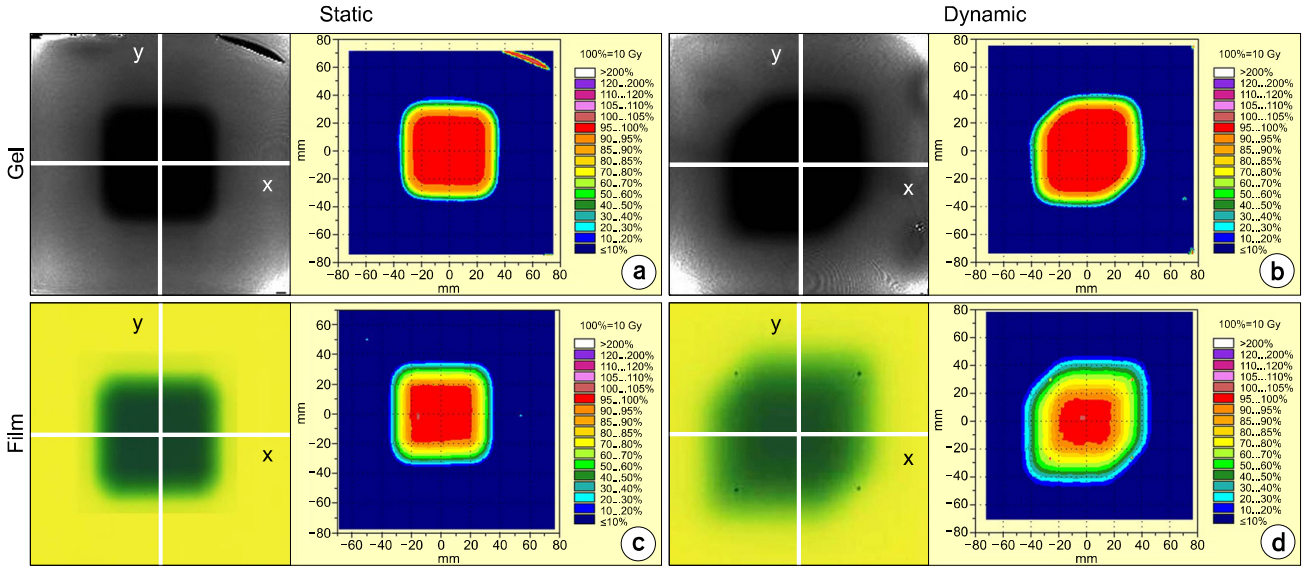


**Fig. 5.** Polymer gel dosimeter and Gafchromic EBT2 film comparison of the scanned images and dose distributions at a depth of 2 cm. Field size: 5×5 $cm^2$, moving distance: ±1.5 cm; (a) static gel, (b) dynamic gel, (c) static film, (d) dynamic film.

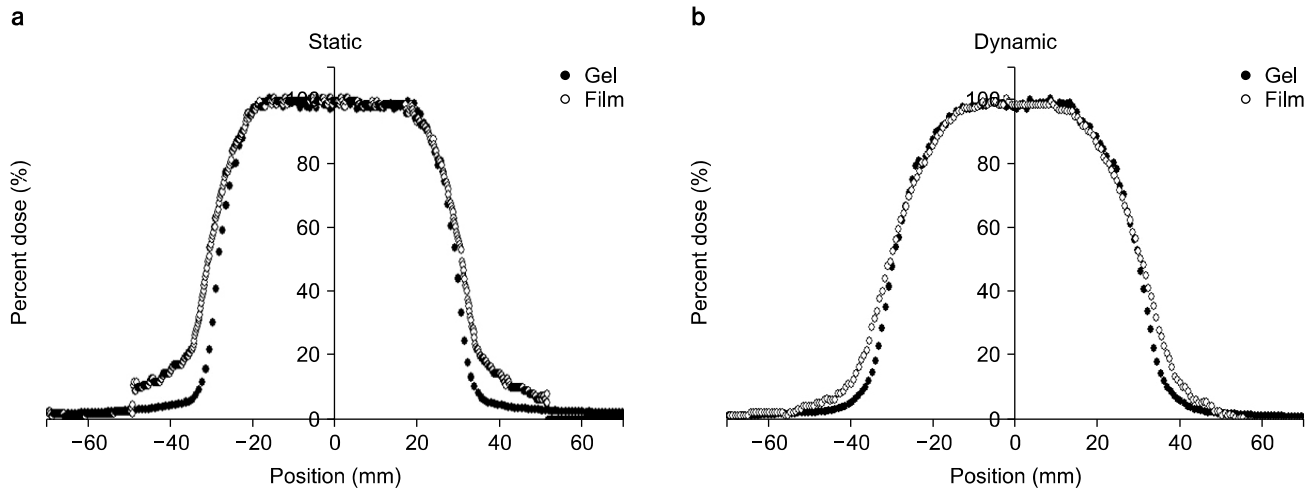


**Fig. 6.** Comparison of the dose profiles for the gel and film in the (a) static state and (b) dynamic state.

**Table 2.** Comparison of the penumbra between the gel dosimeter and the EBT2 film.

| | | Penumbra (mm) | |
|---|---|---|---|
| | | Left | Right |
| Gel | Static | 7.77±0.45 | 7.72±0.59 |
| | Dynamic | 11.03±0.93 | 10.76±0.83 |
| Film | Static | 12.05 | 12.39 |
| | Dynamic | 15.31 | 15.53 |

could not be measured due to the thickness of the acrylic phantom. Thus, the acrylic phantom should be as thin as possible to minimize these complications.

Dose distributions taken at a depth of 2 cm using the gel dosimeter and the film are shown in Fig. 5. With the film, the peripheral low-dose regions appear more diffuse than with the gel dosimeter. With respect to the dynamic state target, the overall shape appeared to be hexagonal after a ±1.5 cm translation in the direction of movement.

In addition, the dose profiles of the static and dynamic targets were obtained using the polymer gel dosimeter and the EBT2 film (Fig. 6). For the gel dosimeter, the flatness was 9.80% for the static target and 12.34% for the dynamic target. In contrast, the flatness that was measured for the film was 11.65% for the static target and 15.93% for the dynamic target. The symmetry values of the dynamic target, which were measured using the gel dosimeter and film, were 2.54% and 4.28% lower than those of the static state, respectively.

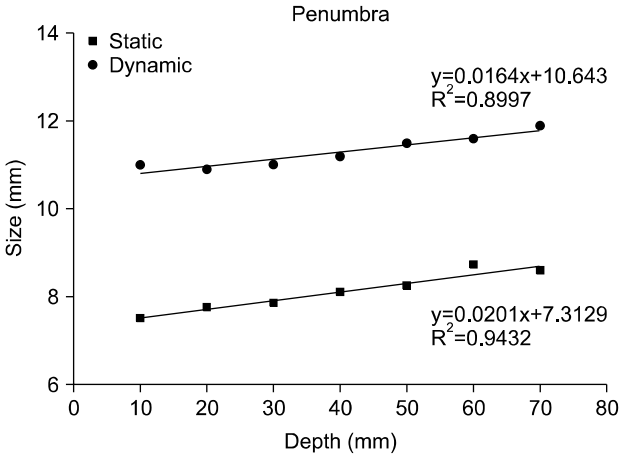


**Fig. 7.** Penumbra depending on the depth of the polymer gel with an SSD of 80 cm and a field size of 5×5 $cm^2$ using the Co-60 gamma ray.

The penumbra width for the static target that was measured using the gel dosimeter averaged 7.75 mm, which was 4.47 mm less than the penumbra that was measured when using the film. This difference may be due to the low optical density of the film.

The penumbra width for the dynamic target was measured using the gel dosimeter with an average width of 10.89 mm, which was 40.5% wider than what was measured for the static target (Table 2).

The measurements of the penumbra depending on depth in the static and dynamic states of the polymer gel dosimeter are

shown in Fig. 7. The penumbra increased as the depth increased from 10 mm to 70 mm.

Also, the penumbra appeared to be larger for the dynamic target than for the static target due to the blurring effect that occurred when the target moved and also due to other geometric factors.

The penumbra measured using the gel dosimeter was larger for the dynamic target than for the static target. The penumbra effect increased with the depth of the target, which is an important factor to consider when planning treatment in clinical radiation therapy.

The polymer gel dosimeter is a 3-dimensional dose measuring instrument that can simultaneously measure the dose distribution and the PDD. However, because it is easily oxidized in air causing polymerization reaction, the polymer gel should be placed in a container. As such, the quality and size of the container can effect the dosimetry, if it is possible to solve these problems, this method is expected to be applicable for confirming dose delivery in respiration gated radiation therapy or intensity modulation radiation therapy.

The present study shows that a gel dosimeter with a respiratory-motion simulator could be used to study the 3-dimensional dose verification of dynamic radiotherapy. As a result of the gel and film experiments, the importance of moving organ dosimetry was confirmed by looking at static and moving states.

Radiation therapy technology concerning dynamic targets in respiration gated radiation therapy is being used more frequently; thus, dose management should be carefully considered when setting the planning target volume for the dynamic target. It is hard to measure the three-dimensional dose distribution with film dosimetry, whereas a polymer gel dosimeter can obtain a three-dimensional dose distribution at once. The combined use of a moving phantom and a polymer gel dosimeter is expected to be useful in 3-dimensional geometric dose evaluation of organ and tumor movements caused by breathing motion.

## CONCLUSION

The preliminary investigations of a polymethacrylic acid gel for PDD, flatness, symmetry, and penumbra were performed in order to find its applicability to therapeutic dynamic targets.

It was shown that the gel dosimeter is applicable as a relative dose evaluation dosimeter for dynamic therapeutic targets. However, when the gel comes in contact with air, a pre-polymerization reaction occurs because of oxidation. Thus the gel must be placed in an acrylic container. As such, the absorbed dose being excessively evaluated due to the effect of the container was observed. Therefore, the container size of the dosimeter has to be large enough for the field size of the beam. Also it is recommended that the material of the container is a tissue equivalent material and the thickness of the container should be as thin as possible. If these requirements are met, it is expected that the gel dosimeter can prove useful in 3 dimensional dynamic dose evaluation.

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# 호흡모의움직임장치를 이용한 정상산소 폴리메타크릴산 겔 선량계의 선량특성

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움직이는 종양의 선량분포는 중합체 겔과 EBT2을 이용하여 필름호흡운동 모의치료기로 분석하였다. 중합체 겔 선량계는 젤라틴, MAA, HQ, THPC, HPLC를 이용하여 합성되었다. 겔 선량계와 EBT2 필름은 5초 간격으로 x축과 y축으로 ±1.5 cm씩 움직이면서 Co-60 감마선을 이용하여 조사하였다. 조사면의 크기 5×5 $cm^2$, SSD 80 cm, 2 cm 깊이에 10 Gy를 조사하였다. 50 mm 깊이에서의 심부선량백분율(PDD)은 이온전리함에서 75.2%였고, 겔 선량계로 측정한 결과 정적상태(static state)에서 82.3%, 동적상태(dynamic state)에서 86.1%였다. 겔 선량계를 이용하여 측정한 동적상태의 반음영(penumbra)은 평균 10.89 mm로 정적상태 반음영의 크기인 7.74 mm 보다 40.5%가 증가하였다. 추가적으로 필름을 이용하여 측정된 반음영의 크기와 비교했을 때 정적상태에서 36.6%, 동적상태에서 29.4%가 작았다.

**중심단어**: 중합체 겔 선량계, 필름, 이동 표적, 선량반응