TLD Dosimetry in HDR Intracavitary Brachytherapy

Chang-Seon Kim, Dae-Sik Yang, Chul-Yong Kim, Myung-Sun Choi

Department of Radiation Oncology, College of Medicine
Korea University, Seoul 136-705, Korea

One consideration of radiation delivery in cervical cancer is the complication of critical organs, e.g., bladder and rectum. The absorbed dose of bladder and rectum in HDR intracavitary brachytherapy is measured indirectly with TLD dosimetry. A method for the complication reduction of bladder and rectum is suggested. For two-hundred cervical cancer patients, follow-up MRI images were reviewed and distances from cervical central axis to bladder and rectum and vaginal wall thickness were measured. The sealed TLDs were placed upon the gauze packing of the ovoids and the distances to the TLDs from the ovoid center were measured in the simulation film and actual doses of bladder and rectum were calculated. From published data, maximal tolerance doses of bladder and rectum were derived and based on the permissible doses per fraction in HDR brachytherapy the packing thicknesses were determined in both directions. The required minimal packing thicknesses for bladder and rectum were 0.43 and 0.92 cm, respectively. The results were compared with computer calculation using the Meisberger polynomial approach. It is our hope this study can be used for a guideline for users in clinic in estimating critical organ dose in bladder and rectum in HDR brachytherapy *in vivo* dosimetry.

Key Words: TLD, HDR Brachytherpy, Cervical Cancer, Bladder, Rectum

INTRODUCTION

In combination with external beam irradiation, high-dose-rate (HDR) intracavitary brachytherapy (ICBT) has become an acceptable treatment for carcinoma of the cervix. In the treatment of cervix carcinoma, the neighboring organs, e.g., bladder and rectum, may receive an unexpected high dose from ICBT resulting in severe complications. The most frequent complications of cervical cancer treatment (hematuria, ulceration, fistula formation) result from a high dose delivered to the portion of the bladder closest to the intracavitary system.[1-7] In contrast, patients who receive a high dose to the entire bladder (e.g., for treatment of bladder carcinoma) tend to have problems with chronic spasm and contraction resulting in reduced bladder capacity. As with the bladder, rectal complications that follow treatment of the cervical carcinoma (hematochezia, fistula) usually reflect sequelae of a high dose treated to a relatively small volume of rectum closest to the intracavitary system.[1-3,5-6,8]

To reduce the complications, minimal

Reprint requests to:
Myung-Sun Choi
Department of Radiation Oncology
Korea University
Seoul 136-705, KOREA
(02) 920-5516
(FAX) (02) 927-1419
E-mail: mschoi98@korea.ac.kr

doses have to delivered to both organs and the doses delivered have to be measured. Direct dose measurement in bladder and rectum, however, is appeared very difficult to realize. The main problem is to be sure that the probe is not positioned at the area of the bladder base and anterior wall of rectum where late radiation reactions occur most frequently.[9,10]

In this study, the absorbed dose of blader and rectum in HDR ICBT is calculated with TLD dosimetry. TLD calibration and dose estimation were also explained. A method for reduction of bladder and rectum complications was estimated in terms of the determination of the packing thickness in the vagina for both directions of bladder and rectum.

MATERIALS AND METHODS

From July 1998 to September 1998, 15 patients with cervical carcinoma treated by combination of external irradiation and HDR intracavitary brachytherapy were selected for the study. All patients were treated with external beam radiation therapy (EBRT) followed by HDR brachytherapy. For EBRT, 10 MV X-rays were applied using four field box technique in daily fractions of 1.8 Gy, 5 times a week for 6 weeks. Total dose was 54 Gy. No midline blocking was used in the external radiation therapy. Brachytherapy was carried out using the Ir-192 HDR remote-controlled afterloading system. HDR brachytherapy was performed with the Manchester type colpostats plus intrauterine tandem or colpostats only three times a week. According to International Commission on Radiation Units and Measurements (ICRU) recommendations, the dose at point A was 3.3, 3.5, and 3.7 Gy/fraction, and the total dose at point A was prescribed as 21, 22.2, or 28 Gy/6 or 8 fractions depending on the Federation of Gynecology and Obstetrics (FIGO) staging of each patient.[11,12] The dose calculation optimization was performed in terms of line A concept saying prescribed fractional dose on the surface enclosed by a volume with 2 cm distance from the sources.

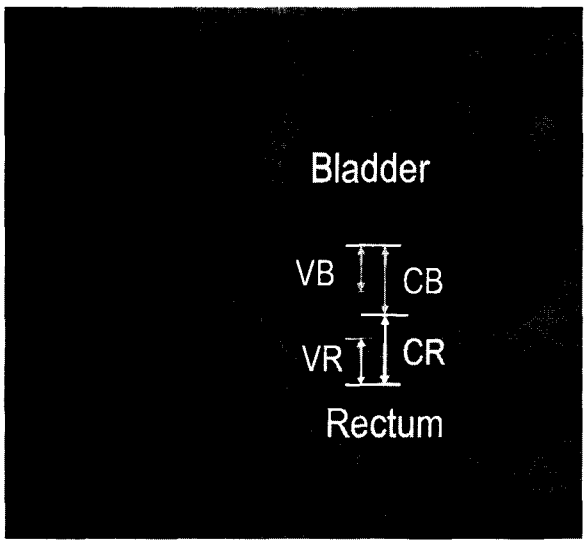

Fig. 1 Definition of distance and thickness. CB and CR=Central axis of the cervix-to-bladder and rectum distance, respectively. VB and VR= vaginal wall thickness in bladder and rectum direction

Almost all patients had the insertion done as an outpatient basis. After the applicator was inserted, wet gauze was used for vaginal packing to push bladder and rectum away from the sources. Anterior-posterior and lateral cross table radiographs were taken for calculation by computer planning to determine the dose to bladder and rectum. At each insertion a Foley catheter was inserted with 7 cm^3 of contrast medium injected into the balloon to identify the bladder base. The posterior vaginal wall was visualized using rectal barium, radio-opaque medium, and the rectal reference points were on the AP lines 5 mm posterior from the vaginal wall.

1. Distance Measurement

From two-hundred cervical cancer patients,

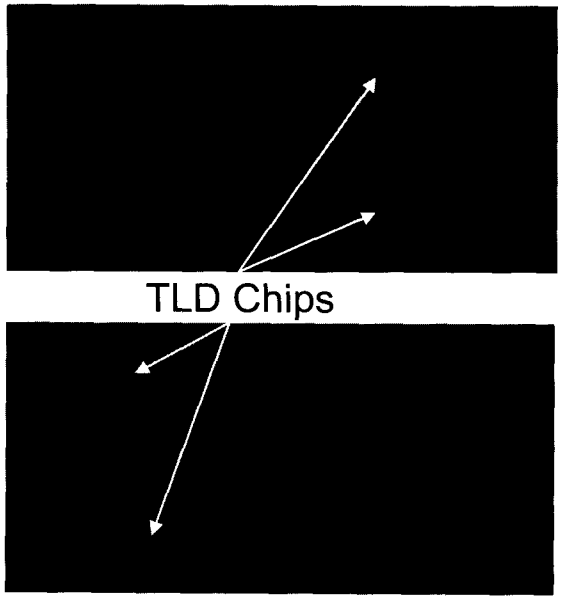

Fig. 2 Location of sealed TLD chips in the case of ovoids plus tandem (upper) and ovoids only (lower) treatment. The TLD chips are placed on the surface of the sterilized gauze packing in bladder and rectum directions. A space is found between the surface of the colpostat and the TLD chips, which is defined as packing thickness for bladder and rectum.

follow-up MRI images were reviewed after radiation therapy were done. Distances from cervical axis to inner wall of bladder and rectum were measured. Vaginal wall thickness from inner vaginal wall to rectum and bladder were also measured. Fig. 1 shows the cervix anatomy in sagittal MRI image. Here four measurement parameters, VB (vaginal wall thickness in bladder direction), VR (vaginal wall thickness in rectum direction), CB (central axis of the cervix to bladder distance) and CR (central axis of the cervix to rectum distance), were shown.

2. Dose Measurement

The *in vivo* TLD measurements were obtained with lithium-fluoride thermoluminescence crystals of similar sensitivity (±3%) (TLD-100 ribbons [3.18 x 3.18 x 0.39 mm^3]; Harshaw Chemical. Solon, Ohio, USA). The preirradiation annealing procedure consisted of 1 hour of heating at 400 ^{0}C followed by 2 hours of heating at 100 ^{0}C. Using an acrylic block phantom, calibration of the TLD ribbons was performed with a dose of 3.5 Gy in a 4 MV x-ray beams. The TLD crystals were measured within 24 hours by using an automatic TLD system (reader model 4000, Harshaw Chemical).

The sealed TLD chips in a sterilized plastic bag was places upon the gauze packing of the ovoids. The gauze packing was visualized by means of radio-opaque medium. Distance from the TLDs to the center of ovoids were measured in posterior-anterial and lateral images in simulation films. Fig. 2 is the typical image in lateral simulation film and the TLD packing can be marginally visualized. Only the cases of well visualized packing gauze and TLD chips were included in the study. For some cases, the location of the bladder were out of the tungsten shielding sector. In the case of large deviation, dose estimation from the TLD dose using the vaginal wall thickness was not guaranteed. Only cases satisfying the criteria mentioned were used for further analysis, 14 for bladder and 19 cases for rectum.

Measured dose in medium using TLD can be expressed as following:[13,14]

$$D_{med} = D_{TLD} \cdot \left(\frac{S}{\rho}\right)_{TLD}^{med}.$$

Here is $\left(\frac{S}{\rho}\right)_{TLD}^{med}$ the ratio of mass collision stopping power for materials medium and TLD at the point of measurement. And the $D_{TLD,}$ radiation dose absorbed in the TLD, can be expressed as

$$D_{TLD} = \left[\left(\frac{S}{\rho}\right)_{cav}^{TLD} \cdot D_{cav} - D_{TLD,bkgd} \right] \cdot f_{lin} \cdot S_{cal}$$

and background reading of the TLD, $D_{TLD,bkgd}$, was extracted from the actual TLD reading to get net TLD response in the tissue. Here $\left(\frac{S}{\rho}\right)_{cav}^{TLD}$, D_{cav}, f_{lin}, and S_{cal} are the ratio of mass collision stopping power for TLD and air cavity, dose measurement using an ionization chamber, the ratio of the sensitivity at the level of TL readout to that for the calibration condition, the TLD sensitivity at the calibration dose, 3.5 Gy, respectively. The factors, f_{lin}, and S_{cal}, were assumed unity because the calibration was performed with the same beam quality. Even though the treatment dose was in the supralinearity region of the TLD response, the dose effect, slight difference in dose between the calibration and measurement, 3.3 and 3.7 Gy, could be ignored and S_{cal}, was assumed to unity.[15] To estimate the actual organ doses of the bladder and rectum from the TLD doses, the values of mean vaginal wall thicknesses in both directions and inverse-square behavior were employed.

This result was compared with the dose calculation from the computer planning used for clinical patient treatment. The dose rate at the point of interest was calculated according to the following formula:

$$\dot{D}(r)=\frac{A\cdot\Gamma}{r^2}\cdot m(r)\cdot f(r,e,A)$$

Where A and Γ are the activity of the source and gamma constant for Iridium, respectively. The Meisberger polynomial is defined as $m(r)= a_0 + a_1 r + a_2 r^2 + a_3 r^3$ and the coefficients, a_0 - a_3, for Ir-192 have following values, a_0=1.0128, a_1= 0.005019, a_2=-0.001178, a_3=-0.00002008. The anisotropy factor, $f(r,e,A)$ is defined the relative dose rate to the value under the angle between the source axis and the direction of point of measurement=90^0. The measured bladder and rectal doses were compared with the results from the dose calculation to determine the packing thickness in both directions.

Table 1 Absorbed dose Measurement at the location of the sealed TLD. To calculate the actual bladder and rectum dose the inverse square law has to be applied.

Distance (cm)	Bladder TLD Dose (cGy)	Distance (cm)	Rectum TLD Dose (cGy)
0.86	667 ± 75.7	1.25	769 ± 67.7
0.87	793 ± 31.1	1.31	620 ± 151.0
1.00	853 ± 49.7	1.38	614 ± 14.9
1.06	666 ± 50.9	1.44	463 ± 26.9
1.25	864 ± 133.0	1.47	405 ± 174.2
1.27	688 ± 56.6	1.50	514 ± 42.1
1.38	755 ± 103.0	1.53	547 ± 42.2
1.47	405 ± 87.2	1.63	510 ± 26.9
1.60	629 ± 47.5	1.67	437 ± 60.1
1.67	406 ± 54.5	1.71	392 ± 53.2
1.72	323 ± 9.7	1.73	433 ± 96.0
1.73	418 ± 102.0	1.75	237 ± 29.2
1.80	548 ± 6.3	1.79	279 ± 74.0
1.81	676 ± 80.8	1.80	377 ± 37.2
		1.81	542 ± 53.0
		1.93	385 ± 27.4
		2.0	271 ± 23.3
		2.07	261 ± 28.7
		2.5	174 ± 14.0

3. Determination of Packing Thickness

Data on the tolerable doses of bladder and rectum was obtained from previous clinical investigation data.[1,7] The tolerable doses for two critical organs were expressed in terms of $TD_{5/5}$ and were 70 Gy and 65 Gy for bladder and rectum, respectively. As the radiation treatment included external therapy and HDR brachytherapy, the fractional doses from each fraction in the HDR brachytherapy to meet the tolerable bladder and rectum doses were estimated. The corresponding packing thicknesses in both directions were calculated.

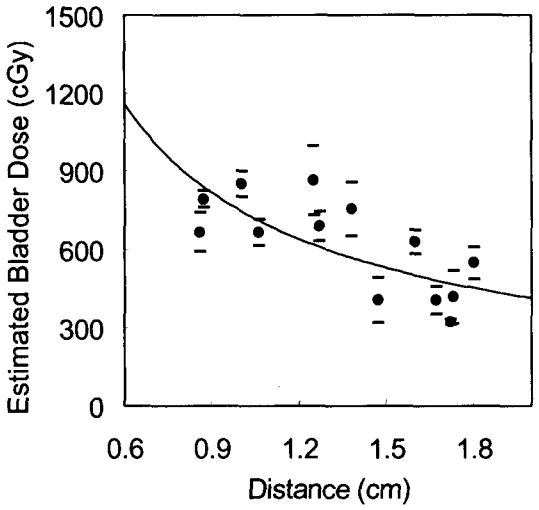

Fig. 3 Estimated Bladder Dose. Bladder TLD dose and mean vaginal wall thickness, 0.62 cm, are used to derive the actual bladder dose. Notice the trend line.

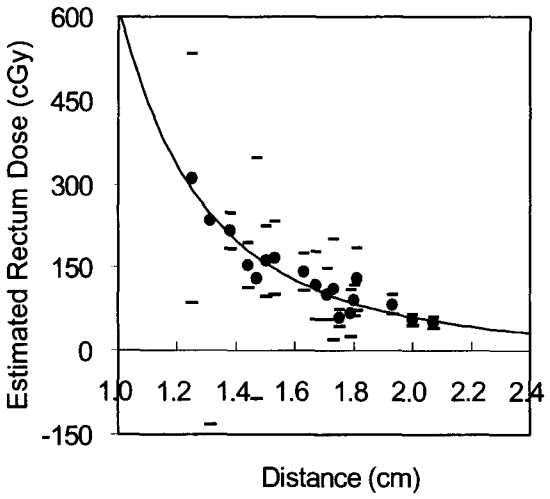

Fig. 4 Estimated Rectum Dose. The mean vaginal wall thickness in rectum direction, 0.63 cm, is used in the calculation. The trend line is shown on the top of the dose data.

RESULTS

1. Distance Measurement

From two-hundred follow-up MRI images, distances from cervical axis to inner wall of bladder and rectum were measured. Mean distance from the central axis of the cervix to inner wall of bladder (CB) and rectum (CR) were measured 1.27 ±0.27 and 1.07 ± 0.29 cm, respectively. Vaginal wall thicknesses from inner wall to bladder (VB) and rectum (VR) were 0.63 ± 0.12 and 0.62 ± 0.13 cm, respectively.

2. Dose Measurement

For 12 cases, measured TLD doses at the location of the thermolumescence chips are shown in the Table 1. The difference in distance accounts for the different patients and/or different trial for the same patient. There were variation in TLD responses among chips used for given measurement conditions. Even though for several points TLD doses do not follow the inverse square law, the change in measured TLD doses can be explained by the inverse square behavior. For bladder, the distance was ranged from 0.86 to 1.81 cm and that for the rectum was 1.25-2.5 cm.

When the vaginal wall thicknesses in the bladder and rectum direction were considered, bladder and rectal doses could be estimated. The resultant doses given to the bladder base for one fraction of the HDR intracavitary brachytherapy treatment were ranged 322-864 cGy for 1.8-0.86 cm distance. For the anterior rectal wall, as the range of the distance from the central axis of the cervix to the rectum was 2.5-1.25 cm, the corresponding dose range was 25-311 cGy. These results were plotted in the Figs. 3 & 4. Here the actual (estimated) doses in the bladder base and the anterior rectal wall were plotted against the distance from the central axis of the cervix. Even though there were a large fluctuation in the estimated bladder and rectum doses, the doses for two critical organs followed the inverse square behavior.

3. Determination of Packing Thickness

Table 2 Required Packing Thicknesses for Bladder and Rectum to Satisfy the $TD_{5/5}$. For the comparison, packing thicknesses from the computer calculation are given.

	Required Packing Thickness (cm)	
	TLD Measurement	Calculation
Bladder	0.43	0.31
Rectum	0.92	0.92

The tolerable doses for two critical organs were expressed in terms of $TD_{5/5}$ and were 70 Gy and 65 Gy for bladder and rectum, respectively. As the whole series included EBRT and ICBT, after the EBRT of total 54 Gy in bladder and rectum was completed, the fractional dose for tolerable doses in HDR brachytherapy was calculated. as 2.67 and 1.83 Gy for bladder and rectum, respectively. Based on the Figs. 3 & 4, the calculated packing thicknesses to meet this requirements were 0.43 and 0.92 cm for bladder and rectum, respectively (Table 2). A difference in packing thickness in bladder direction was found from the computer calculation and the result were 0.31 cm.

DISCUSSION

In this study the concept of point dose and not the whole organ dose is used in the maximal doses for bladder and rectum. If the doses considered are whole organ doses, the fractional doses for bladder and rectum have to be changed and in turn the minimal packing thicknesses. The whole organ doses, however, are less meaningful in this approach because the dose gradient in the whole organs are significant and the dose in top of the bladder is far from the significant complications. This is true in the rectal dose calculation. One possible approach is the midline dose concept saying that the dose of the bladder at the level of the center, which is in between the dose level of the bottom and the top of the bladder. This is, however, not practical for the dose calculation in the critical organs. Even though the dose in the level of the center is far below the maximal permissible dose, any bladder complication will be occurred as the dose at the bottom of the bladder is far beyond the permissible dose.

Based on this study, the treatment procedure in the HDR intracavitary brachytherapy is recommended to be changed to satisfy the bladder and rectum dose limitation through both external radiation therapy and intracavitary brachytherapy. Excessive dosage to the organ at risk, is possible to be reduced within permissible range simply by increasing the distance between the organs and the applicator by means of rearrangement or additional vaginal packing in the same arrangement. Care has to be used for the packing as the minor change of the packing thickness results in wide variation in bladder and rectal dose. Therefore before the radiation, radiographs have to be taken to verify whether the proper packing thickness is obtained.

For the HDR intracavitary brachytherapy, six fractions are scheduled for most of patients. The interfraction variation of the vaginal packing thicknesses in bladder and rectum directions have to be examined.[16] The variation has its potential treatment impact and possible changes in measured dose of critical organs and it is necessary to do a time-course study for the same patient over the HDR brachytherapy treatment. Further study to handle this possibility is planned and on the way.

CONCLUSION

Based on our study, required minimum distance from the ovoid center to anterior wall of rectum and base of bladder are 2.78 and 2.31 cm, respectively, to satisfy the $TD_{5/5}$. Corresponding

packing thicknesses are 0.43 and 0.92 cm for bladder and rectum, respectively. For the routine patient treatment using HDR brachytherapy, a lateral simulation film should be obtained with the applicator positioned and the packing thickness be determined to keep separation of the bladder and rectum from the center of the applicator. It is necessary to rearrange the vaginal gauze in order to increase the distance between the base of bladder and the anterior wall of the rectum and the applicator. This study is hoped to be used for a guideline for users in clinic in estimating critical organ dose in bladder and rectum *in vivo* HDR brachytherapy.

ACKNOWLEDGMENT

This work was partially supported by a grant (Principle Investigator: Chang-Seon Kim) of the Korea University Medical Science Research Center (KUMSRC), 1999.

REFERENCES

1. Rubin P.: The law and order of radiation sensitivity, absolute vs. relative. Vaeth J.M., Meyer J.L.: Radiation Tolerance of Normal Tissues. Frontiers of Radiation Therapy and Oncology 23:7-40 (1989)
2. Stryker J.A., Bartholomew M., Velkley D.E., Cunningham D.E., Mortel R., Craycraft G., Shafer A.: Bladder and Rectal Complications following Radiotherapy for Cervix Cancer. Gynecologic Oncology 29:1-11 (1988)
3. Kapp K.S., Stuecklschweiger G.F., Kapp D.S., Poschauko J., Pickel H., Hackl A.: Carcinoma of the cervix: analysis of complications after primary external beam radiation and Ir-192 HDR brachytherapy. 42:143-153 (1997)
4. Kuipers Tj., Visser A.G.: Technical aspects of bladder dosimetry in intracavitary irradiation of cervix carcinoma. Radiotherapy and Oncology 7:7-12 (1986)
5. Montana G.S., Fowler W.C.: Carcinoma of the Cervix: analysis of bladder and rectal radiation dose and complications. Int. J. Radiation Oncology Biol. Phys. 16:95-100 (1989)
6. Eifel P.J.: Clinical Intracavitary Systems for Treatment of Gynecologic Malignancies. Williamson J.F., Thomadsen B.R., Nath R.: *Brachytherapy Physics*. Medical Physics, Madison, WI (1995), pp. 411-426
7. Emami B., Lyman J., Brown A., Coia L., Goitein M., Munzenrider J.E., Shank B., Solin L.J., Wesson M.: Tolerance of Normal Tissue to Therapeutic Irradiation. Int. J. Radiation Oncology Biol. Phys. 21:109-122 (1991)
8. Uno T., Itami J., Aruga M., Kotaka K., Fujimoto H., Sato T., Minoura S., Ito H.: High Dose Rate Brachytherapy for Carcinoma of the Cervix: Risk Factors for Late Rectal Complications. Int. J. Radiation Oncology Biol. Phys. 40:615-621 (1998)
9. Stuecklschweiger G.F., Arian-Schad K.S., Poiter E., Poschauko J., Hackl A.: Bladder and Rectal Dose of Gynecologic High-Dose-rate Implants: Comparison of Orthogonal Radiographic Measurements with in Vivo and CT-assisted Measurements. Radiology 181:889-894 (1991)
10. Cunningham D.E., Stryker J.A., Velkley D.E., Chung C.K.: Routine Clinical Estimation of Rectal, Rectosigmoidal, and Bladder Doses from Intracavitary Brachytherapy in the Treatment of Carcinoma of the Cervix. Int. J. Radiation Oncology Biol. Phys. 7:653-660 (1981)
11. ICRU Report 38: *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology*. International Commission on Radiation Units and Measurements, Bethesda, MD (1985)
12. Lahtinen T., Tenhunen M., Vaeyrynen M.: ICRU reference points and maximum doses of rectum and bladder in intracavitary radiotherapy. Radiotherapy and Oncology 28:174-176 (1993)

13. Cho S.H., Muller-Runkel R., Hanson W.F.: Determination of the tissue attenuation factor along two major axes of a high dose rate (HDR) ^{192}Ir source. Med. Phys. 26:1492-1497 (1999)
14. Pradhan A.S., Quast U.: In-phantom response of LiF TLD-100 for dosimetry of ^{192}Ir HDR source. Med. Phys. 27:1025-1029 (2000)
15. Mobit P.N., Mayles P., Nahum A.E.: The quality dependence of LiF TLD in megavoltage photon beams: Monte Carlo simulation and experiments. Phys. Med. Biol. 41:387-398 (1996)
16. Bahena J.H., Martinez A., Yan D., Mele E., Edmunson G., Brown D., Hardy M., Brabbins D., Gustafson G.: Spatial Reproducibility of the Ring and Tandem High-Dose Rate Cervix Applicator. Int. J. Radiation Oncology Biol. Phys. 41:13-19 (1998)

고선량률 강내 근접치료시 열형광량계를 이용한 선량측정법

고려대학교 의과대학 방사선종양학과

김 창선, 양 대식, 김 철용, 최 명선

자궁경부암 환자의 방사선 조사시 고려하여야 할 사항 중 한가지는 결정 장기인 방광 및 직장의 부작용이다. 강내 고선량률 근접 치료시 방광과 직장의 흡수선량을 열형광량계 선량측정법을 이용하여 간접적으로 측정하였다. 방광 및 직장의 부작용을 줄일 수 있는 방법이 제안되었다. 방사선치료 후 예후관찰 중인 200명의 자궁경부암 환자의 자기공명 영상에서 자궁경부의 중심축에서 방광 및 직장 그리고 자궁벽의 두께를 측정하였다. 밀봉시킨 열형광량계를 오보이드의 팩킹거즈 위에 놓고 씨뮬레이션 필름 상에서 오보이드의 중심에서부터의 거리를 측정한 후 실제의 방광과 직장의 흡수선량을 계산하였다. 발표된 연구결과들에서 방광 및 직장의 최대 견딤선량을 계산하였고 고선량률 근접치료 1회당의 허용선량을 토대로 양방향의 팩킹두께를 알아냈다. 방광과 직장방향의 최소의 팩킹두께는 각각 0.43 과 0.92 cm 이었다. 이 결과를 마이스버거 다항식을 이용한 계산결과와 비교하였다. 본 연구에서 제시한 방법이 임상에서 고선량률 근접 치료시 방광과 직장 같은 결정장기의 흡수선량을 평가하는 방법으로 사용되기를 바란다.

중심단어: 열형광량계, 고선량률 근접치료, 자궁경부암, 방광, 직장