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(Original article)

Influence of the dose to the laryngeal cancer by the difference in radiation beam energy

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Summary

We investigated the usefulness of Gafchromic MD-55 film (Nuclear Associates, Inc.) for measuring the radiation doses on the radiotherapy of laryngeal cancers.

Since larynx has thin wedge-shaped structure in anterior neck adjacent to airway, the radiation doses to the lesion may be diminished because of build-up and build-down. So, the dose has been measured with conventional measuring systems such as thermoluminescent dosimetry (TLD). However, it was not possible to evaluate the dose distribution correctly using TLD, because it is impossible to float a TLD chip in an air cavity. In this study, we employed Gafchromic MD-55 film as a dosimeter, for it can be set on the area of interest and with a measurability of dose range of 3 to 100 Gy, though it has no energy dependency. And this radiometer is composition near the soft tissue of the human body. The dose distributions to larynx were investigated with this film using neck phantom under each radiation beam energy of 4, 6 and 10 MV x-rays. Our neck phantom is made from acrylic resin and simulates a normal larynx on the basis of image information of computed tomography (CT).

Moreover we observed secondary build-up and build-down curves in tissue in the vicinity of air cavities, especially at 10 MV x-rays. These findings suggest that patients with T1-T2 glottic cancers with anterior commissure invasion may receive more effective treatment with 4 MV x-rays rather than with 6 MV and 10 MV x-rays.

Keywords : Gafchromic MD-55 film, radiation dose, build-up, build-down, glottic cancer

Introduction

Radiotherapy is an established method for treatment of T1 glottic cancers. Since the larynx has thin a wedge-shaped structure in the anterior neck adjacent to the airway, the radiation doses to the lesion may be diminished because of build-up and build-down. Build-down is the opposite phenomenon of build-up, that is, when the incidence of the x-rays are carried out from high density materials to low density materials, the dose diminution occurs on the interface between them. That is, the selection of radiation beam energy influences the local control in the larynx. In the treatment of lesions located in the upper respiratory tract, the radiation beams must often pass through an air cavity before reaching the surface layers of the lesion. Under such conditions, the air-tumor tissue interface will not be in a state of

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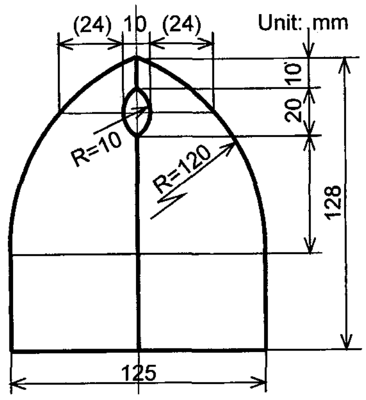
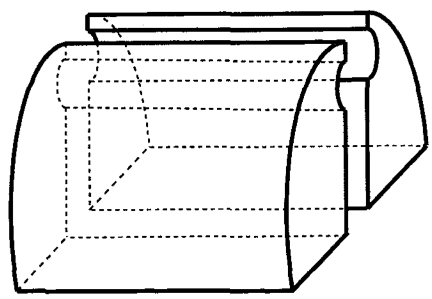
electronic equilibrium. This lack of electronic equilibrium could result in an underdose to the air-tissue interface. That is, there may be insufficient build-up of the higher-energy beam after traversing an air cavity such as the larynx, due to a disruption of the electron equilibrium at the air-soft-tissue interface, so that the contralateral vocal cord might be underdosed when a parallel opposed lateral field arrangement is used. It has been reported that this effect is more severe for the higher energy photon beams than previously measured for ^{60}Co radiation beams[1,2]. So, the dose has been measured with conventional measuring systems such as thermoluminescent dosimetry (TLD)[3]. However, it was not possible to evaluate the dose distribution correctly using TLD, because it is impossible to float a TLD chip in the air cavity.

In this study, we employed Gafchromic MD-55 film as a dosimeter, for it can be set on the area of interest and with a measurability of dose range of 3 to 100 Gy, moreover it has no energy dependency. And the sensor material is similar in its electron stopping powers to water and muscle[4]. It is also similar to water and muscle in terms of mass energy-absorption coefficients for photons of energies greater than 100 keV[4]. For these reasons, it can measure an absorbed dose in the location, where is in a state of lack of secondary electron equilibrium such as the larynx. The piece of Gafchromic MD-55 film was set in the phantom for measuring dose distributions of the area from the anterior skin surface to posterior through the airway in a median sagittal plane. Then, the dose distributions to the area were investigated with this dosimetry system using the neck phantom under each radiation beam energy of 4, 6 and 10 MV x-rays respectively.

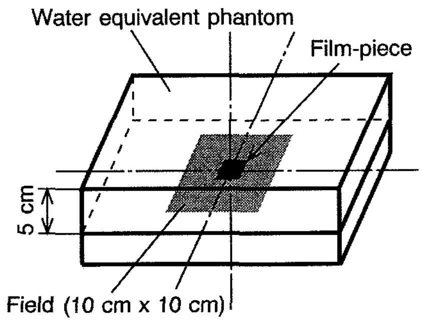


(a) Transverse view of the neck phantom

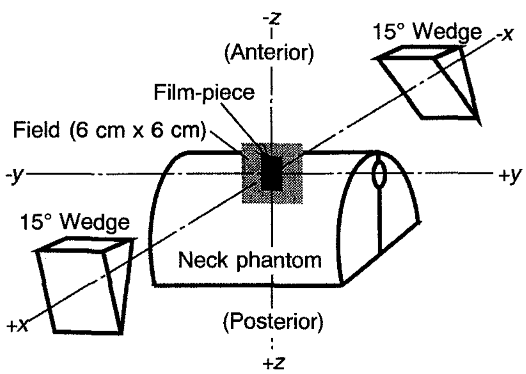


(b) The external view of the phantom

Fig. 1 Neck phantom is made from acrylic resin and simulates a normal larynx on the basis of image information of CT.



(a) Irradiation for calibration curves



(b) Irradiation for measuring dose distribution

Fig. 2 Experiment arrangement plans.

Materials and Methods

1. Experimental arrangements for measuring doses

Our neck phantom as shown in Fig. 1 is made from acrylic resin and simulates a normal larynx on the basis of image information of CT (Computed Tomography). For the phantom to simulate the neck and larynx as closely as possible, the internal contour of the air cavity also had to be accurately machined in the phantom. The phantom form is bilateral-symmetry, and the phantom can be divided into two in a median plane (Fig. 1 (b)). Fig. 2 (a) shows the arrangement of irradiation to a film-piece of Gafchromic MD-55 film in order to produce a calibration curve of film density to dose. The film-piece was irradiated at a 5 cm depth in a 40 × 40 cm^2 water equivalent slab phantom with 10 cm × 10 cm field size. Fig. 2 (b) shows the arrangement of irradiation to a film-piece in order to measure dose distribution corresponding to the anatomic location of the larynx in a median sagittal plane. The linear accelerators (MEVATRON M2/6327, and MEVATRON77: TOSHIBA MEDICAL SYSTEMS CO. LTD.) were used. Two laterally opposed (left-right) fields (6 cm × 6 cm field size), were set up isocentrically at the mid-plane of the phantom at a source-axis-distance (SAD) of 100 cm. Furthermore, a 15-degree wedge filter was used in order to improve dose homogeneity. This arrangement is exactly the same as the actual treatment arrangement. The piece of Gafchromic MD-55 film was set in the phantom for measuring dose distributions of the area from the anterior skin surface to posterior through the airway in a median sagittal plane as shown in Fig. 2 (b).

2. Calibration curve of Gafchromic MD-55 film density to dose

Gafchromic MD-55 film simplifies the evaluation of dose distribution because of its low sensitivity to normal room light and its non-requirement of processing. The relative dose distribution is ascertained according to the relative optical densities of exposed areas. For this experiment, film-pieces of size 2 cm × 2 cm were cut from an unexposed 5.0 inch × 5.0 inch sheet of Gafchromic MD-55 film[5]. They were cut and labeled 24 hours before irradiation in order to avoid any possible changes in film sensitivity due to the trauma of pressing or cutting the film. Furthermore the optical densities of the unexposed pieces of film were measured by the laser densitometer (Model 1710: Computerized Medical Systems, Inc.) with the 0.25 ± 0.05 mm spot size in the dark room[6]. For producing an optical density versus dose calibration curve, some of the 2 cm × 2 cm pieces of Gafchromic MD-55 film were irradiated to known doses in increments of about 2 Gy as shown in Fig. 2 (a). Twenty-four hours after the irradiation, the optical densities of the films were measured under the same conditions as the un-irradiated pieces. The net optical densities were calculated by subtracting the measured optical densities of the irradiated Gafchromic MD-55 films from that of unirradiated Gafchromic MD-55 film. This process can remove uniformity of optical density in each unirradiated piece. A second order polynomial function was used to produce the optical densities (pixel values) versus the dose calibration curve.

3. Measurement of dose distribution

The phantom was irradiated using 4, 6 and 10 MV x-rays. In this measurement, film-pieces each of size 20 mm × 40 mm were cut from an unexposed 5.0 inch × 5.0 inch sheet of Gafchromic MD-55 film. They were cut and labeled 24 hours before irradiation as in the case of the calibration curve. Moreover, the 20 mm × 40 mm film-piece was set in the phantom for measuring dose distributions of the area from the anterior skin surface to posterior through the airway in the median sagittal plane as shown in Fig. 3 (a), (b). In our facility, the practical prescription dose for T1 glottis cancer is 66 Gy (2 Gy × 33 fractions). However 20 Gy was decided as the total dose to the area of interest in the phantom for the following reasons; the limitation of load to the linear accelerators had to be considered, and Gafchromic MD-55 film has dose rate and energy-independent response. It has been reported that the calibration curve of Gafchromic MD-55 film density to the dose was close to a straight line[7-9]. The total dose was decided from the balance of the actual dose and the above reasons, and also, some research reports about this film in the same dose that have been published[1,2]. Treatment monitor sets were calculated to deliver 20 Gy tumor dose to a target volume in the phantom corresponding to the anatomic location of the vocal cord and anterior commissure, based on computer-generated dosimetry (FOCUS:

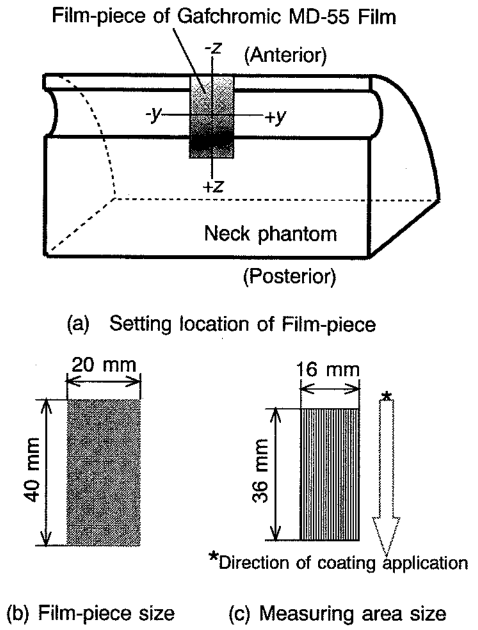


Fig. 3 Setting location and measuring area size of film-piece of Gafchromic MD-55 film.

Computerized Medical Systems, Inc.). The optical densities (pixel values) of the irradiated films as shown in Fig. 2 (b) were measured by the same procedure as well as the films for the calibration curve. The dose distributions in the target area were obtained through the process which turns the densities (pixel values) into doses with the calibration curve. Truncation of the convolved dose distribution near the edge of the distribution causes larger discrepancies at the edges of the data. So, as the edge of each piece of cut film appeared on the calculation, it was excluded. All the scanning of a piece of film was performed parallel (the direction of the z-axis) to the direction of the coating application as shown in Fig. 3 (b)[4]. Also, the above two processes were performed on the data or film-pieces for the calibration curve. The 17 mm × 17 mm area on the film-pieces for the calibration curve was employed as data area.

Results

1. Calibration curve of film density to dose

Fig. 4 shows the relationship between the film's net pixel values (optical densities) measured with the densitometer versus the given total dose. The film does not have dose rate and energy-independent response down to 100 Gy[4]. Those character-

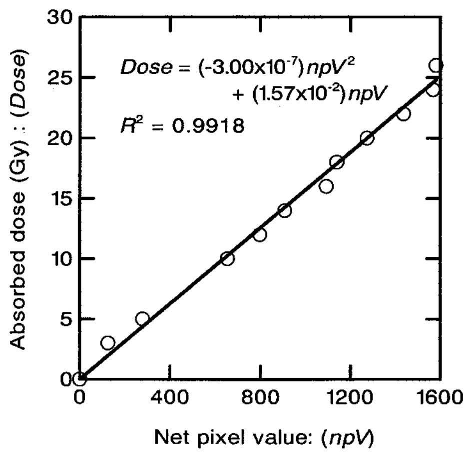


Fig. 4 Net pixel value (Optical density) versus dose Calibration Curve.

istics were actually checked in our pre-experiment too. So, these film's pixel values were obtained from averaging the net data of 4, 6 and 10 MV x-rays. This relationship was used for all data for measuring distribution of dose with phantom.

2. Measurement of dose distribution

Fig. 5 shows the dose distributions of the area from the anterior skin surface to the posterior through the air way at x=0, in 4, 6 and 10 MV x-rays. The pseudo-color dose distribution generated by Gafchromic MD-55 film in the region of the phantom was shown. These dose distributions are expressed with the gray scale of 20 gradations in 20 Gy. Moreover, each dose profile was shown in Fig. 6. They were dose profiles at the isocenter (y=0) and in the region of -18 mm≦z≦+18 mm. Furthermore, the average curves of the profiles from y=-8 mm to +8 mm in each x-ray, were shown in Fig. 7. Moreover, the increase-rates or decrease-rates to 20 Gy in seven z-positions (Dc1 - Dc7), shown in Fig. 7, were shown with the standard deviation in Table 1. The data position of Dc3 (z=-10 mm), Dc4 (z=0 mm) and Dc5 (z=+10 mm) correspond to the anatomic location of the anterior commissure, the central part of the air cavity and the posterior commissure respectively. Only in the case of 4 MV x-rays did the dose at the anterior commissure attain the target dose. It is included to the area of 100 % (20 Gy). From the information obtained before and behind the position of z=0 mm, the influence of the air cavity can be known.

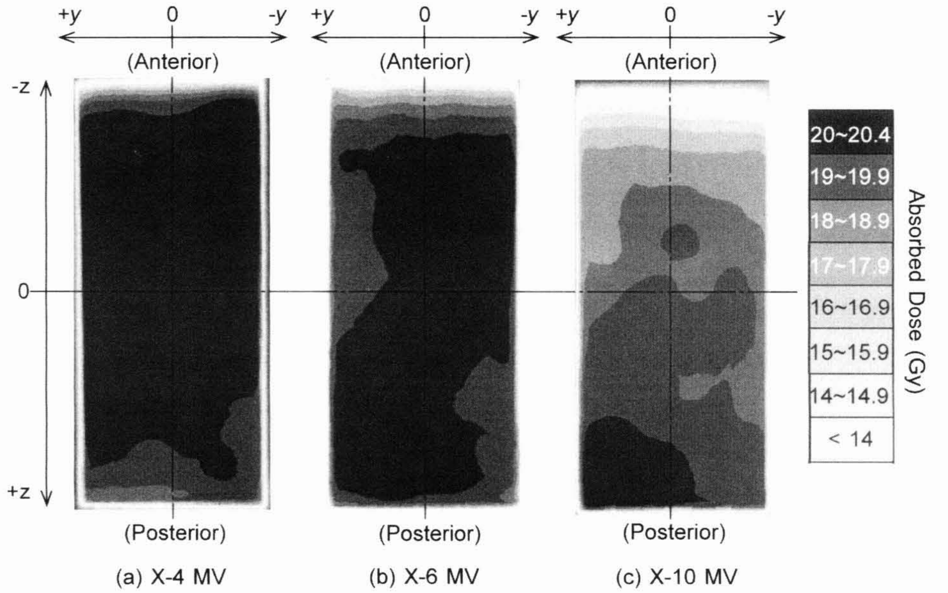


Fig. 5 Gray scale display of dose distributions in 4, 6, 10 MV x-rays.

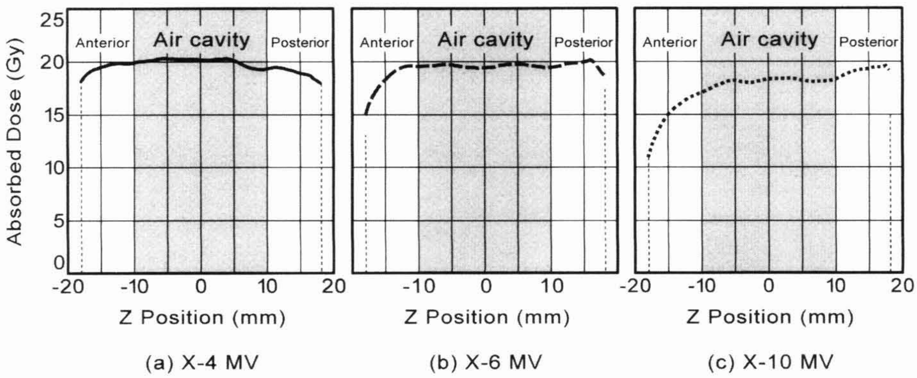


Fig. 6 Dose profiles at the isocenter (y=0, -18 mm≦z ≦+18 mm) in 4, 6, 10 MV x-rays.

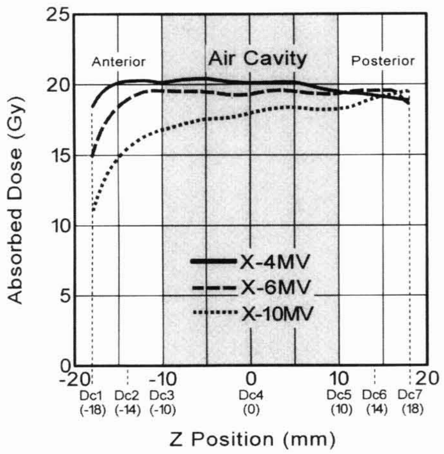


Fig. 7 Curves obtained from averaging profiles (-8 mm ≦ y ≦+8 mm) in 4, 6, 10 MV x-rays.

	Percentage variations (±Std.Dev.) (%)		
Data No.	X-4 MV	X-6 MV	X-10 MV
Dc1	−7.70 (±2.25)	−25.59 (±1.07)	−44.51 (±1.45)
Dc2	+1.25 (±3.30)	− 5.46 (±0.81)	−21.95 (±0.58)
*Dc3	+0.85 (±2.92)	− 2.22 (±2.37)	−15.65 (±0.75)
Dc4	+0.55 (±1.81)	− 3.42 (±2.22)	− 9.39 (±1.14)
**Dc5	−3.15 (±1.46)	− 3.25 (±2.30)	− 7.83 (±1.68)
Dc6	−4.70 (±0.83)	− 2.24 (±1.87)	− 3.73 (±2.67)
Dc7	−5.60 (±0.81)	− 6.96 (±1.53)	− 4.98 (±5.19)

* Anterior commissure
** Posterior commissure
These percentage variations were calculated for 20 Gy.

Table 1 The dose diminution decreasing rate on the Gafchromic MD-55 film. (These percentage variations were calculated for 20 Gy.)

Discussion

Only the 4 MV x-rays dose at the anterior commissure attained the target dose as shown in Fig. 7 and Table 1. These trends are considered to mean clearly that the differences in energy, that is, the build-up regions, differ. Since the build-up depth is as deep as high x-ray energy, the target dose is attained in the posterior area. CT-based computer simulation is rapidly becoming the accepted standard of practice for pre-treatment simulation for a wide variety of clinical protocols. In our facility, the treatment planning of the laryngeal cancer determines the prescription dose on the treatment planning system. The treatment planning system used FOCUS (Computerized Medical Systems, Inc.). The calculation algorithm used is Clarkson.Then, the distributions by the film and the simulation data were compared. Fig. 8 shows CT-based computer generated dose distributions in the phantom for 4, 6 and 10 MV x-rays. Fig. 9 shows the dose profiles which were picked out from the simulation data corresponding to the region to the posterior commissure from

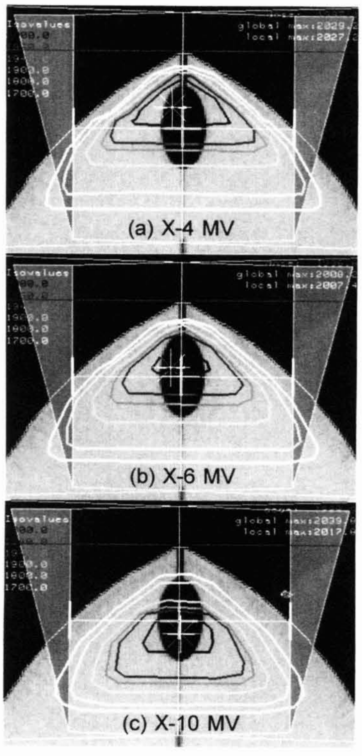


Fig. 8 CT-based computer generated dose distributions by treatment planning system (FOCUS) in 4, 6, 10 MV x-rays.

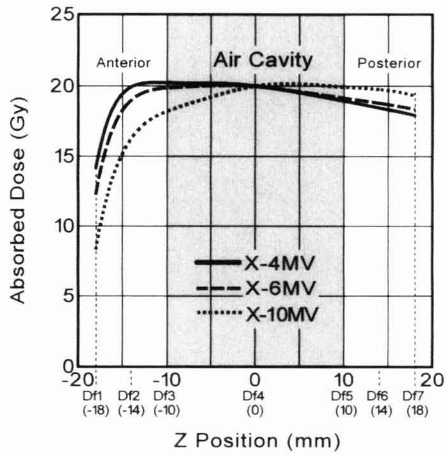


Fig. 9 Dose profiles of CT-based computer generated dose distributions by treatment planning system (FOCUS) in 4, 6, 10 MV x-rays.

	Percentage variations (±Std.Dev.) (%)		
Data No.	X-4 MV	X-6 MV	X-10 MV
Dfc1	-28.27	-37.85	-56.93
Dfc2	− 0.05	− 5.27	-19.15
*Dfc3	+ 0.78	− 0.75	− 8.46
Dfc4	+ 0.04	− 0.02	− 0.02
**Dfc5	− 5.78	− 4.60	− 0.47
Dfc6	− 7.96	− 6.23	− 1.23
Dfc7	-11.05	− 8.89	− 3.79

* Anterior commissure
** Posterior commissure
These percentage variations were calculated for 20 Gy.

Table 2 The dose diminution decreasing rate on the treatment planning system (FOCUS). (These percentage variations were calculated for 20 Gy.)

the anterior skin surface through the airway in the median sagittal plane. Furthermore, percentage variations for 20 Gy at seven points (Dc1-7) including the anterior commissure, the isocenter and the posterior commissure in the region were shown in Table 2. In 4 MV and 6 MV x-rays, the Gafchromic MD-55 film showed the almost same result as the treatment planning system at anterior commissure except thin region of neck. However, the values by Gafchromic MD-55 film in 6 MV x-ray showed trend to fall a little, in the airway region. Furthermore, this downward tendency in 10 MV became strong. The target dose for the anterior commissure was not acquired, but both values were nearly in agreement in the thick region of the neck phantom. As one of the rea-

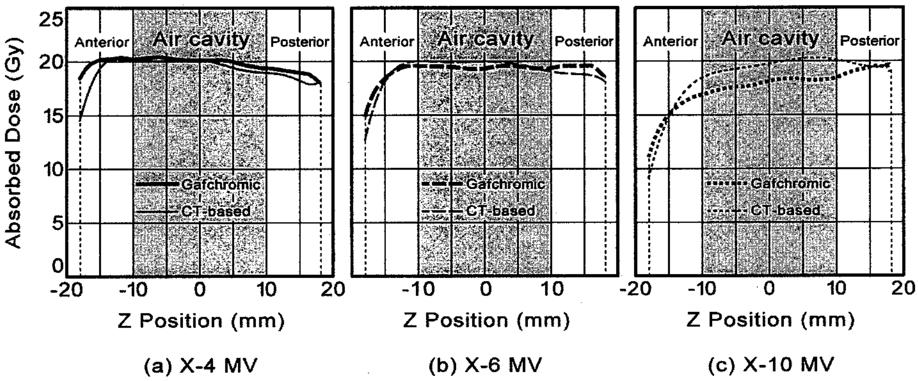


Fig. 10 Comparisons of profiles by Gafchromic MD-55 film and by CT-based computer generated dose distributions in 4, 6, 10 MV x-rays.

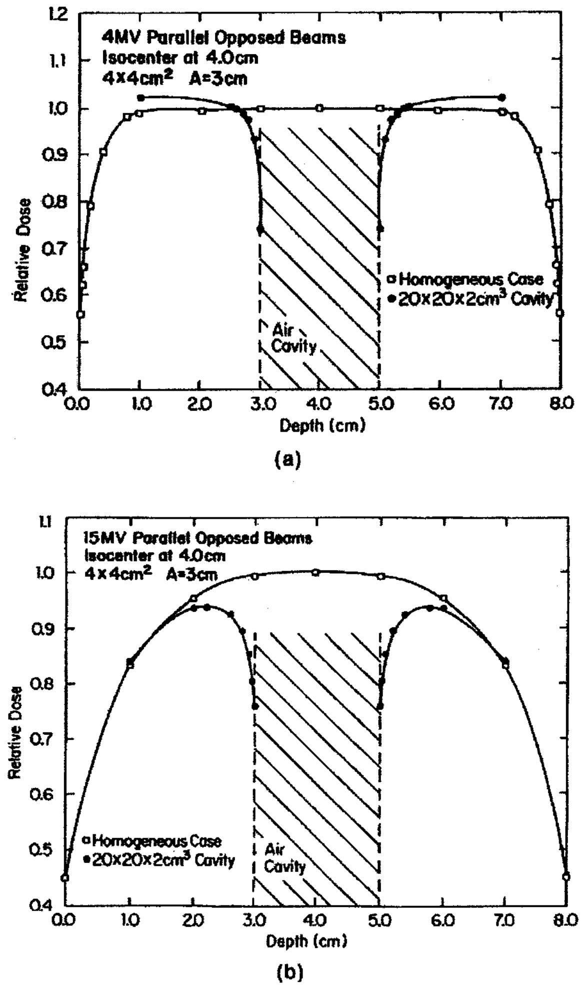


Fig. 11 Parallel opposed relative dose for layer cavity geometry (2.0 cm air gap) where all points are normalized to the center (4.0 cm) for the homogeneous case for a 4 cm × 4 cm field. (a), 4 MV. (b), 15 MV.

sons, it is thought that the calculation algorithm of the treatment planning system is related. The presence of air cavities can produce significantly higher or lower dose readings, depending on photon energy, size and shape of the cavity, and distance to the interfaces. The underdosing that occurs at air-tissue interfaces is due to nonequilibrium conditions. The calculation algorithm of the treatment planning system does not take unhomogeneous correction into consideration. In order to solve this problem, we have to wait for the algorithm calculable with practical speed into which Monte Carlo calculations are introduced. By comparing the measurement by Gafchromic MD-55 film with the treatment planning system, we could observe the underdosing in the airway. Klein et al. reported on the influence of air cavities as shown in Fig. 11[10]. For the homogeneous test, two opposed beams were placed isocentrically at 4.0 cm depth for a phantom thickness of 8.0 cm, in their study. They then introduced a layered air cavity 2.0 cm thick in the middle of their phantom, giving 3.0 cm of tissue followed by the cavity, followed by a further 3.0 cm of tissue. Again, they added the readings from two opposed beams and normalized to the homogeneous isocenter readings. From their result, it is considered that the differences of our curves in Fig. 10 at air-tissue interfaces is appropriate although the phantom form is different.

Conclusions

We investigated the usefulness of Gafchromic MD-55 film for measuring the radiation doses on the radiotherapy of laryngeal cancers. Our experimental data indicate that, it was possible to express clearly that the difference in x-rays energy influenced the dose distribution by Gafchromic MD-55 film. Special care was taken in handling and calibrating these dosimeters to reduce the uncertainties in the accuracy and precision of these dosimeters. In 4 MV and 6 MV x-rays, the Gafchromic MD-55 film showed almost the same result as the treatment planning system at anterior commissure except in a thin region of neck. However, the values build-up and build-down curves in tissue in the vicinity of air cavities, especially at 10 MV x-rays. These findings, suggest that patients with T1 glottic cancers with anterior commissure invasion may be better managed with 4 MV x-rays rather than with 6 MV and 10 MV x-rays.

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放射線エネルギーの違いによる喉頭癌における吸収線量の影響

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要　約

T１声門癌に対して放射線治療を単独で行うのは確立している方法である。しかし，頚部は解剖学的に複雑であり，前方に薄いV字形で，喉頭が気道に隣接している構造を持つので，病巣への線量は build-up と build-down の影響による線量低下が生じることが考えられる。すなわち，放射線エネルギーの選択が喉頭癌の局所的制御に影響を及ぼすと言える。この影響は，より高い放射線エネルギーでは，それに伴いより強く起きるということが基礎実験にて報告されている。また，それらの線量測定は，熱ルミネセンス線量計(TLD) のような従来の測定システムで測定されていた。しかし，空気空洞へ TLD を単体で浮かせ線量を正確に測定し評価を行うのは困難である。本研究において，我々は Gafchromic MD-55 film (Nuclear Associates, Inc.) を使用し測定した。Gafchromic MD-55 film は，フィルムタイプ線量計でありエネルギー依存性がなく，３〜100 Gyを測定可能であり，アクリル製頚部ファントムの空気組織境界面及び，空洞部に線量計を容易に精度良く配置することが可能である。また，この線量計は人体の軟部組織に近い組成である。そこで，４，６および10 MVの各エネルギーでこの線量計を用いてエネルギーの違いによる，頚部ファントムを用いて喉頭の線量評価を行った。

その結果，我々は，特に放射線エネルギー10 MVで頚部ファントムにおける，前部組織－組織空洞境界面－空洞部の一連した build-up および build-down を線量計で評価することができた。これらの研究の結果、前交連浸潤を有するT１－T２に相当する声門癌患者は，放射線エネルギー６MVおよび10 MVではなく，４MVを用いることによって，より効果的な放射線治療を行えると推測できる。

キーワード：Gafchromic MD-55 film, radiation dose, build-up, build-down, glottic cancer

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