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Synergy of Build up Effect from Application of Magnetic Bolus in Radiotherapy Area

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In radiotherapy, bolus is used for the superficial tumor, but there in limitation in the dose distribution control. Therefore, the changes in the dose distribution according to the application of the magnetic bolus are to be evaluated. In the case of not applying the bolus, and in applications of the magnetic bolus and the non-magnetic bolus, OSLD (Optically Stimulated Luminescence Dosimeter) was used to measure the dosage for each depth for comparison. In the case of not applying the bolus and applying the non-magnetic bolus, the difference according to the depth correction was a maximum of 2.17 %, and the difference according to applying the non-magnetic bolus and the magnetic bolus was a maximum of 4.39 %. In addition, the changes in the dose value according to the application of magnetic bolus showed average increase of 2.39 from the surface to 7 mm, and there was average decrease of 0.43 % in the depth of 8 cm-15 cm. Therefore, in the radiotherapy, it is considered that the increase in therapeutic effect and normal organ protective effect can be expected according to the application of the magnetic bolus.

Keywords : build up effect, magnetic bolus, ferrofluid, radiotherapy

1. Introduction

Radiotherapy is a therapeutic method of using high-energy electromagnetic radiation to cut the DNA chain of the cancer cells inside the body to inhibit the proliferation and to kill the cancer cells [1]. In the radiotherapy, various therapeutic techniques and instruments are applied according to the territories existing with cancer cells [2, 3]. Among them, as shown in Fig. 1, the instrument most generally applied for the superficial tumor is bolus [4, 5]. The bolus is a flexible substance that has the non-magnetic tissue-equivalent electron-density, and is applied by covering the tumor surface [6-8]. Generally, materials of the bolus mostly use polyethylene or pine resin, or rise or water or paraffin etc. [9-12], and the reason that the bolus is most commonly used in superficial tumor is because the maximum dose is realized on the tumor site according to the application of bolus [13, 14]. When the electromagnetic radiation is irradiated into the body, scattered rays are generated in all directions by the interaction with the tissues, and maximum dose is composed in a fixed depth inside the body [15, 16]. Here, when the bolus with the fixed depth of thickness covers the skin surface, the point of maximum dose moves to the tumor site [17-20]. Therefore, maximum dose is delivered to the tumor site, and the normal organs that must be protected are delivered with lower dose to enhance the effect of the radiotherapy. The decrease in dose according to the application of bolus is shown in Formula 1, and the generation of scattered ray is shown in Formula 2.

$$I = I_0 e^{-\mu x} \tag{1}$$

I : Final intensity of radiation
I_0 : Primary intensity of radiation
μ : Mass attenuation coefficient
x : Thickness of material

$$\psi(r) = e^{ikz} + f(\theta)\frac{e^{ikr}}{r} \tag{2}$$

$\mathbf{r}$: Vector position of (x, y, z)
r : $|\mathbf{r}|$
e^{ikz} : Incoming plane wave with the wavenumber (k)

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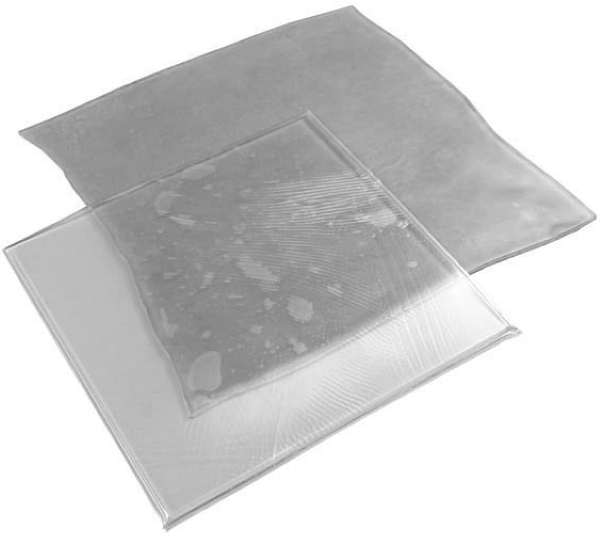

Fig. 1. The bolus for radiotherapy.

along the z aixs
θ : Scattering angle
$f(\theta)$: Scattering amplitude

However, there are limitations in the amount of scattered ray generation according to the application of bolus, and the energy distribution of the scattered rays is similar to the developmental distribution of the scattered rays inside the body, so there are limitations in reducing the dose on the normal organs that must be protected. In addition, the electron rays generated in the scattering process contribute greatly in killing the cells inside the body, so controlling the electron rays is very important. Therefore, a magnetic substance should be applied to the bolus to control the electron rays, so it is considered that there will be changes in the dose distribution by producing & applying such magnetic bolus. In this study, the changes in the dose distribution in the body according to the application of magnetic bolus are to be evaluated to verify the synergic effect of the build-up effect.

2. Materials and Methods

2.1. Equipment and materials

1. Medial LINACs : CLINAC-iX (VARIAN, USA)
2. Optically Stimulated Luminescence Detector (LANDAUER, USA)
3. Portable OSL dosimeter reader : MicroStar® InLight® Reader (LANDAUER, USA)
4. Handmade magnetic bolus : Apply a magnetic material ($FeCl_2$+$2FeCl_3$+$3NH_3H_2O$) to the 250 mm × 250 mm × 5 mm bolus in 1 mm thickness, and material of using bolus is polyethylene.
5. Cubic Phantom : Solid Phantom (CIRS, USA) 30 cm × 30 cm × 0.1 cm

2.2. Experimental

For the production of the magnetic bolus, Ferrofluid is applied in 1 mm thickness to the non-magnetic bolus that is commonly used. To evaluate the changes in the dose distribution inside the body according to the application of the magnetic bolus, the cases of not applying the bolus, applying the non-magnetic bolus, and applying the magnetic bolus were divided and compared. The changes in the dose distribution in the body result in a rapid change on the surface, so 1 mm thickness of phantom was used to be set in the total height of 5 cm for acquiring the dose value per mm unit. As shown in Fig. 2, it was divided into the phantom not placed with the bolus, the phantom placed with the non-magnetic bolus, and the phantom placed with the magnetic bolus, and measurement was enabled from the surface to 10 cm depth in 1 mm depth interval. Here, the irradiation condition was to be Gantry angle of 0°, Collimator angle of 0°, Field size 10 × 10 cm^2, Target to phantom surface distance of 100 cm, Electromagnetic radiation energy of 6 MV (Mega Volt), and Exposure dose of 100 MU (Monitor Unit). For the dose measurement, OSLD (Optically Stimulated Luminescence Dosimeter) (Al_2O_3:C) was used for the measurement, and the measurement values were acquired through the exclusive reader. The dose measurement process of

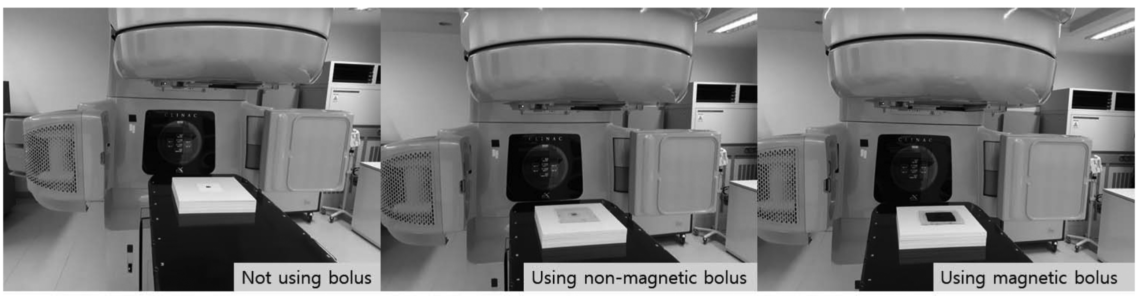

Fig. 2. Image by experimental conditions.

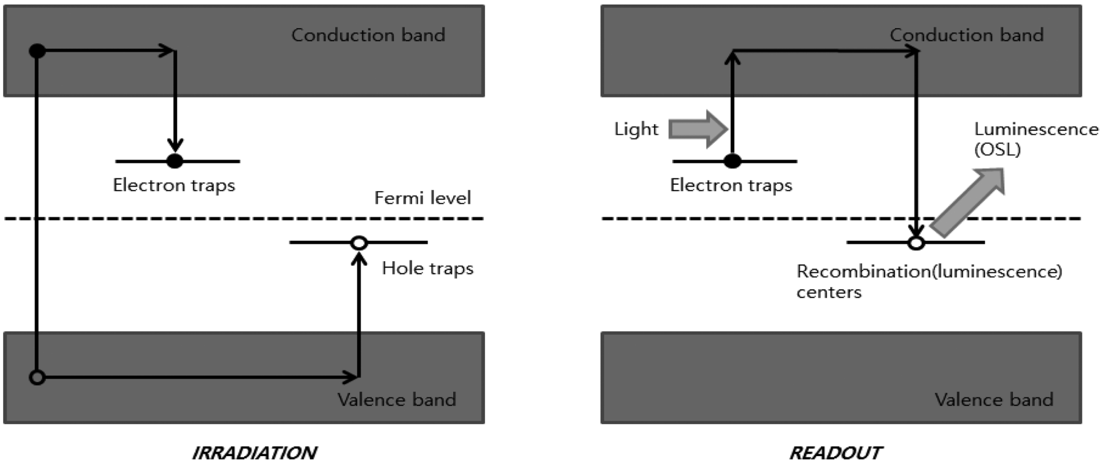

Fig. 3. Measurement process of OSLD.

the OSLD is shown in Fig. 3, and the correction of the dose value is shown as in Formula 3.

$$D_w = M_{corr} \cdot N_{D,w} \cdot k_F \cdot k_L \cdot k_Q \cdot k_\theta \tag{3}$$

D_w : Dose
M_{corr} : Signal
$N_{D,w}$: Calibration coefficient
k_Q : Beam quality correction factor
k_L : Dose non-linearity correction factor
k_F : Fading correction factor
k_θ : Angular dependence correction factor

The dose value according to the depth was measured 5 times each to compare the dose value for each depth. In addition, the dose value when applying the non-magnetic bolus was compared with the case of not applying the bolus through the correction by theoretical basis. And the dose value for each depth according to the application of non-magnetic bolus was compared with the dose value for each depth according to the application of magnetic bolus, and the changes in the dose value near the prescribed dose and the changes in the dose value over the fixed depth located with the organ for protection were compared to evaluate the usefulness according to the application of the magnetic bolus.

3. Result

In the case of not applying the bolus, the dose value for each depth is shown in Fig. 4, and the dose value for each depth when applying the non-magnetic bolus is shown in Fig. 5. And the dose value for each depth when applying the magnetic bolus is shown in Fig. 6. And the difference of the result value on not applying the bolus with moving the average dose value to 5 mm to the surface and the

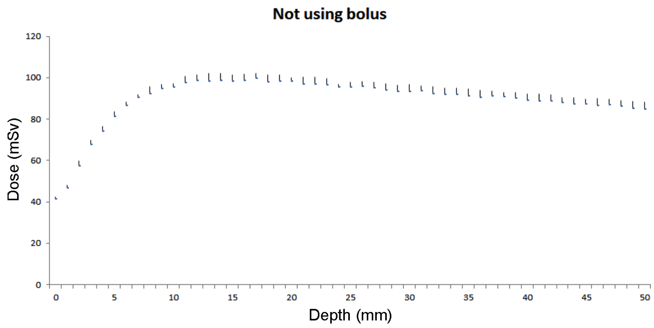

Fig. 4. Dose value by depth when no bolus is applied.

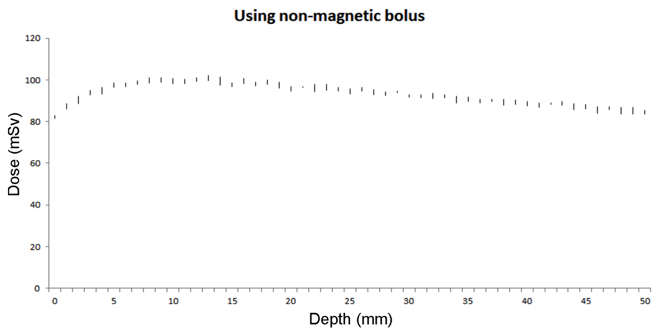

Fig. 5. Dose value by depth when non-magnetic bolus is applied.

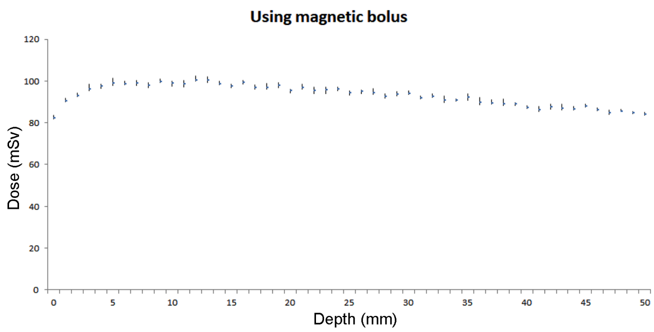

Fig. 6. Dose value by depth when magnetic bolus is applied.

Table 1. Difference in depth between the case where the bolus is not applied and the case where the non-magnetic bolus is applied.

Depth (mm)	Difference value (%)	Depth (mm)	Difference value (%)
1	99.78	26	98.91
2	99.58	27	100.64
3	99.21	28	100.64
4	99.49	29	100.04
5	98.74	30	101.02
6	101.58	31	99.20
7	97.83	32	100.04
8	99.34	33	99.36
9	99.77	34	100.60
10	99.67	35	99.25
11	99.11	36	100.26
12	98.87	37	99.42
13	99.12	38	99.62
14	101.06	39	100.16
15	99.68	40	100.54
16	98.17	41	100.08
17	100.97	42	98.46
18	99.39	43	100.16
19	100.24	44	101.49
20	101.24	45	100.46
21	98.96	46	100.65
22	99.25	47	100.01
23	98.97	48	100.22
24	100.67	49	101.06
25	100.80	50	101.59

Table 2. Difference in depth between the case where the non-magnetic bolus is applied and the case where the magnetic bolus is applied.

Depth (mm)	Difference value (%)	Depth (mm)	Difference value (%)
1	100.44	26	100.19
2	104.39	27	99.94
3	103.05	28	100.34
4	102.95	29	99.63
5	103.31	30	99.80
6	101.40	31	102.05
7	101.15	32	100.00
8	99.96	33	101.28
9	97.82	34	98.80
10	99.86	35	100.54
11	100.00	36	102.10
12	99.88	37	100.21
13	100.53	38	99.32
14	99.50	39	99.84
15	99.00	40	99.56
16	100.29	41	98.63
17	100.52	42	98.80
18	98.81	43	99.42
19	98.67	44	98.59
20	100.55	45	98.89
21	99.73	46	101.57
22	100.63	47	101.09
23	99.87	48	98.43
24	99.73	49	100.65
25	100.56	50	99.59

average dose value when applying the non-magnetic bolus is shown in Table 1 to be maximum of 2.17 % or less for each depth and the variation value of 0.88 %. In addition, the difference of the average dose value when applying the non-magnetic bolus and the average dose value when applying the magnetic bolus is shown in Table 2 to be maximum of 4.39 % or less for each depth and the variation value of 1.33 %. Besides, the sum value of the difference from the surface to 15 mm depth occupies 44.43 % of the total difference sum value.

4. Discussion

The application of commonly-used non-magnetic bolus has the purpose of approving the intended dose near the tumor through the dose movement of the superficial tumor and approving relatively lower dose to the organs for protection. However, as for the non-magnetic bolus, the electron-density of the human body is in the equivalent substance to make the control of scattered electron rays to be impossible. But, according to the application of magnetic bolus, the scattered electron rays are controlled to increase the dose on the intended tumor site, and to relatively reduce the dose on the organs for protection. There were various existing studies conducted according to the application of non-magnetic bolus, but there was no study conducted on the application of magnetic bolus, so through this study, it is considered that availability of the magnetic bolus must be secured through various study activities. In this study, the evaluation of the dose value according to the magnetic bolus depth was performed with solid phantom, so the continuous changes in the dose were not applied to disable the smooth graph, but if the evaluation using water phantom is possible by improving the evaluation method in the future, it is considered that the accuracy will be enhanced in evaluating the difference. Moreover, if the magnetic density can be improved even more through the development of magnetic substances, it is considered that the synergic effect of the build-up effect by the magnetic bolus will be enhanced. The reason for using the solid phantom instead of the water phantom used in the general depth dose measurement is that when the water phantom is used, the positional reproducibility error of the magnetic bolus occurs and the flat setting is impossible due to the flexibleness of the bolus. In this study, the reason why the high dose appears from the surface to a certain depth is thought to be the accumulation of scattering electrons by the magnetic field and generation of scattering radiation by the magnetic material. Also, when the depth is deeper, the dose decreases slightly due to the deviation of the scattering electrons in a certain range.

5. Conclusion

As a result of verifying the changes in the dose distribution according to the application of magnetic bolus, the difference between the cases of applying the non-magnetic bolus and the magnetic bolus was shown more clearly compared to the difference with depth correction on when not applying the bolus and when applying the non-magnetic bolus. Especially, from the surface to 7 cm that is near the tumor, average of 2.39 % dose increase effect could be expected, and in the depth of 8 cm-15 cm, average of 0.43 % dose reduction effect could be expected. In future radiotherapy, the increase in therapeutic effect and the decrease in adverse effects can be expected by applying the magnetic bolus.

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