Chamber to Chamber Variations of a Cylindrical Ionization Chamber for the Calibration of an ^{192}Ir Brachytherapy Source Based on an Absorbed Dose to Water Standards

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This work is for the preliminary study for the calibration of an ^{192}Ir brachytherapy source based on an absorbed dose to water standards. In order to calibrate brachytherapy sources based on absorbed dose to water standards using a clyndirical ionization chamber, the beam quality correction factor k_{Q,Q_o} is needed. In this study k_{Q,Q_o}s were determined by both Monte carlo simulation and semiexperimental methods because of the realistic difficulties to use primary standards to measure an absolute dose at a specified distance. The 5 different serial numbers of the PTW30013 chamber type were selected for this study. While chamber to chamber variations ran up to maximum 4.0% with the generic k^{gen}_{Q,Q_0}, the chamber to chamber variations were within a maximum deviation of 0.5% with the individual k^{ind}_{Q,Q_0}. The results show why and how important ionization chambers must be calibrated individually for the calibration of ^{192}Ir brachytherapy sources based on absorbed dose to water standards. We hope that in the near future users will be able to calibrate the brachytherapy sources in terms of an absorbed dose to water, the quantity of interest in the treatment, instead of an air kerma strength just as the calibration in the high energy photon and electron beam.

Key Words: Beam quality correction factor, Absorbed dose to water, Ionization chamber, Primary standards

INTRODUCTION

For the calibration of the high energy photon and electron beams, air-kerma based calibration system has been replaced by the absorbed dose to water calibration system. The protocols based on the absorbed dose to water aim to provide directly the absorbed dose to water, which is just the quantity of interest in the clinical treatment, instead of air kerma. This work is for the preliminary study for the calibration of an brachytherapy source based on an ^{192}Ir absorbed dose to water standards.

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Calibrations in clinical practice for the HDR brachy therapy ^{192}Ir sources are usually performed in air in terms of air kerma rate using the well-type chambers or jig phantoms. The strength of brachytherapy sources is still commonly specified by the air-kerma strength. As in the case of high energy photon and electron beams, the so-called air-kerma is not the quantity of interest in the brachytherapy treatment and the absorbed dose to water is just the quantity of interest. Some authors have been trying to develop the primary standards for the calibration of HDR ^{192}Ir brachytherapy sources based on absorbed dose to water standards.[1,2]

Every user has the cylindrical ionization chamber types, which are routinely used for the calibration of the high energy photon and electron beams. In order to calibrate brachytherapy sources based on an absorbed dose water using an ionization chamber, the beam quality correction factor k_{Q,Q_0} is needed. The absorbed dose to water based protocols,[3,4] however, recommend that in the low and medium energy X-ray generic values of k^{gen}_{Q,Q_0} shoud not be used because of large chamber to chamber variations in energy response within a same type ionization chamber and that chambers must be calibrated individually. The ^{192}Ir source has a broad spectrum ranging from about 61 keV to 1.4 MeV or so and it means this source might be considered roughly to belong to low and medium energy range.[5-8)]

According to the recommendations by the protocols, the individual chambers must be provided with directly measured values of k^{ind}_{Q,Q_0} in the ^{192}Ir source. Until now, the PSDLs doesn't provide users with directly measured values of k^{ind}_{Q,Q_0} for the ^{192}Ir source, that is to say, there are no primary standards dedicated to brachytherapy sources based on an absorbed dose to water (under development by some authors). To be unfortunate, users should wait more long years to be able to calibrate brachytherapy sources including ^{192}Ir source based on an absorbed dose to water standards.

It is a reality that the individual beam quality correction factors k^{ind}_{Q,Q_0} of the chamber of interest cannot be obtained for the ^{192}Ir source, and we tried to investigate, first, chamber to chamber variations of an PTW30013 ionization chamber when as a makeshift the generic value of k^{gen}_{Q,Q_0} was used, which is calculated through Monte Carlo simulation, and, second, chamber to chamber variations when chambers are given imaginarily individual calibrations, where "imaginarily" means that the dose RTP system delivers is used as an imaginary absolute dose as if determined by primary standards.

MATERIALS AND METHODS

1. Theory and formalism for the calculation of generic values of k^{gen}_{Q,Q_0}

An absorbed dose to water in the clinical user beam of beam quality Q is calculated according to TRS-398 or TG-51 protocol as follows.

$$D_w = M_Q \cdot N_{D,W,Q_0} \cdot k_{Q,Q_0} \tag{1}$$

Where M_Q is the reading of the dosimeter corrected for the ambient air pressure and temperature, N_{D,W,Q_0} the calibration factor in terms of absorbed dose to water, and k_{Q,Q_0} corrects for the effects of the difference between the reference beam quality Q_0 and the clinical user beam quality Q.

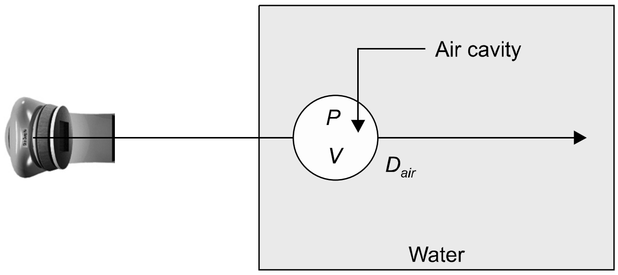

Fig. 1. Relation of charges collected in the air cavity and the absorbed dose to the air cavity. The air cavity has the volume of V and ρ the density of ρ. The charge M_Q collected in the air cavity can be derived from the absorbed dose to the air cavity D_{air} if D_{air} could be determined.

The factor k_{Q,Q_0}can be expressed as

$$k_{Q,Q_0} = \frac{N_{D,W,Q}}{N_{D,W,Q_0}} = \frac{N_{D,W,Ir192}}{N_{D,W,Cobalt}} = k^{gen}_{Q,Q_0} \tag{2}$$

For the calculation of $N_{D,W,cobalt}$ and $N_{D,W,Ir192}$, Eldorado8 cobalt therapy machine was modeled using BEAM code and the PTW30013 Chamber and the Ir-192 source were coded using EGSnrcCPP code.

If the factor $N_{D,W,Q}$ for the beam quality Q could be known, the absorbed dose to water in the same beam is given by

$$D_W = M_Q \cdot N_{D,W,Q} \tag{3}$$

The calibration correction factor $N_{D,W,Q}$ is given from the equation (3) by

$$N_{D,W,Q} = \frac{D_W}{M_Q} \tag{4}$$

Therefore, if D_W and M_Q could be determined $N_{D,W,Q}$ could be calculated. While the absorbed dose to water D_W can be obtained directly from Monte carlo simulation, charge collected in the cavity M_Q is derived (not directly but indirectly) from the absorbed dose to the air cavity D_{air}, which is also obtained from Monte carlo simulation.

If The M_Q is known, the absorbed dose to the air cavity D_{air} is given by

$$D_{air} = \frac{M_Q}{m_{air}} \cdot \left(W/e \right) \quad (5)$$

From equation (5), M_Q is given by

$$M_Q = \frac{D_{air}}{\left(W/e \right)} \cdot m_{air} = \frac{D_{air}}{\left(W/e \right)} \cdot \left(\rho V \right) \quad (6)$$

Where m_{air} is the mass of the air in the cavity and (W/e), 33.97[J/C]was used in this calculation, is the mean energy expended in air per ion pair formed and its. If the Volume V and density ρ of the air cavity are known, M_Q can be determined from the equation (6) because D_{air} can be calculated from the Monte carlo simulation.

The equation (4) of the calibration correction factor $N_{D,W,Q}$ is now rewritten using the equation (6) as follows.

$$N_{D,W,Q} = \frac{D_W}{D_{air}} \cdot \frac{\left(W/e \right)}{m_{air}} \quad (7)$$

The calibration correction factors $N_{D,W,cobalt}$ and $N_{D,W,Ir192}$ are given as follows.

$$N_{D,W,Co60} = \frac{D_w^{Co60}}{D_{air}^{Co60}} \cdot \frac{\left(W/e \right)}{m_{air}} \quad (8)$$

$$N_{D,W,Ir192} = \frac{D_w^{Ir192}}{D_{air}^{Ir192}} \cdot \frac{\left(W/e \right)}{m_{air}} \quad (9)$$

In order to calculate $N_{D,W,cobalt}$ and $N_{D,W,Ir192}$ according to (8) and (9) the geometry in Fig 2. was used. The absorbed dose for the Co-60 beam was calculated at 5.0 cm depth in a 10×10 cm^2 field size at an SSD of 100 and the reference distance to obtain the absorbed dose for Ir-192 source was chosen 5.0 cm. At first the absorbed dose to water D_W at the reference depth (distance as for Ir-192 source) was determined using Monte carlo simulation. The PTW30013 chamber was then positioned at the same reference depth (distance as for Ir-192 source) and the absorbed dose to air cavity $D_{air}$was determined. The D_W and D_{air} determined by Monte Carlo simulation were used to calculate $N_{D,W,cobalt}$ and $N_{D,W,Ir192}$ in equation (8) and (9).

The model of Eldorado8 as the Cobalt teletherapy machine was chosen and modeled using BEAM code (Fig. 3). Phase space file was obtained at the plane of SSD 100 cm and used as the source file of the cobalt beam. The geometry of both the Ir-192 source and the PTW30013 ionization chamber was modeled using EGSnrcCPP code. The absorbed doses in both the Co-60 sysetm an the Ir-192 source system were determined by EGSnrcCPP code.

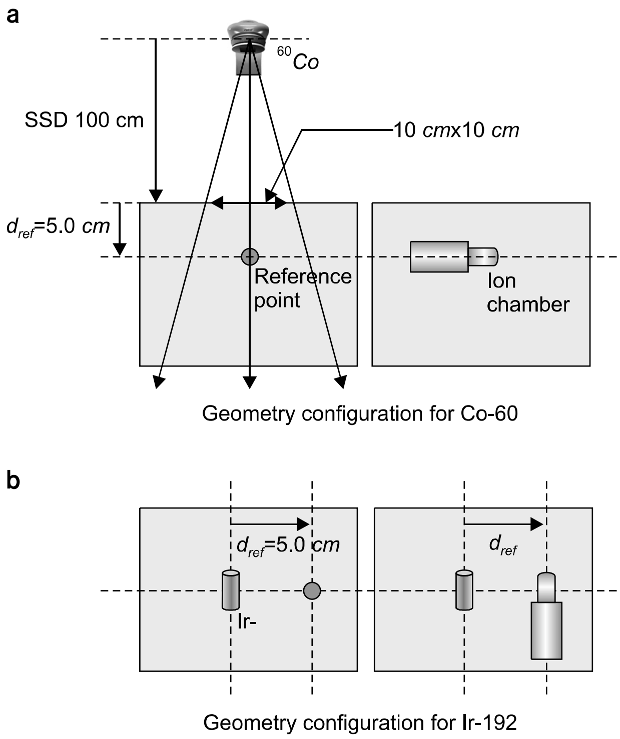

Fig. 2. Geometry configuration for the Monte carlo simuation to calculate $N_{D,W,Q}$. (a) is for Co-60 irradiation where the absorbed doses both at the reference point and an ion chamber were calculated at 5.0 cm depth in a 10×10 cm^2 field size at an SSD of 100 and (b) for the Ir912 irradiation. Both the reference depth d_{ref} for Co-60 simulation and the reference distance for the Ir912 simulation were chosen 5.0 cm. The absorbed doses both in the reference point and the chamber air cavity were calculated by Monte carlo simulation.

2. The individual values of k_{Q,Q_0}^{ind} for the particular chamber

According to recommendations given in the protocols based on an absorbed dose to water, the ionization chambers must be calibrated individually in the low and medium energy X-ray. It means that the generic value of k_{Q,Q_0}^{ind} for a given ionization chamber type should not be used in this range of energy. The

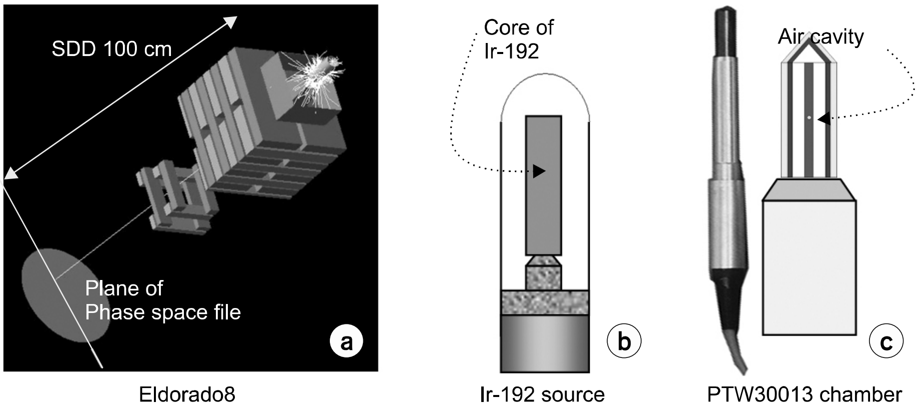

Fig. 3. Schematic diagram of simulation geometries used in this work. (a) shows diagram of Eldorado 8 teletherapy machine, (b) Ir-192 source, and (c) PTW30013 ionization chamber. The Eldorado 8 model was modeled using BEAM code and the phase space file was obtained at the plane of SSD 100 cm in a 10×10 cm^2 field size. Both Ir-192 source and PTW30013 chamber were modeled using EGSnrcCPP code.

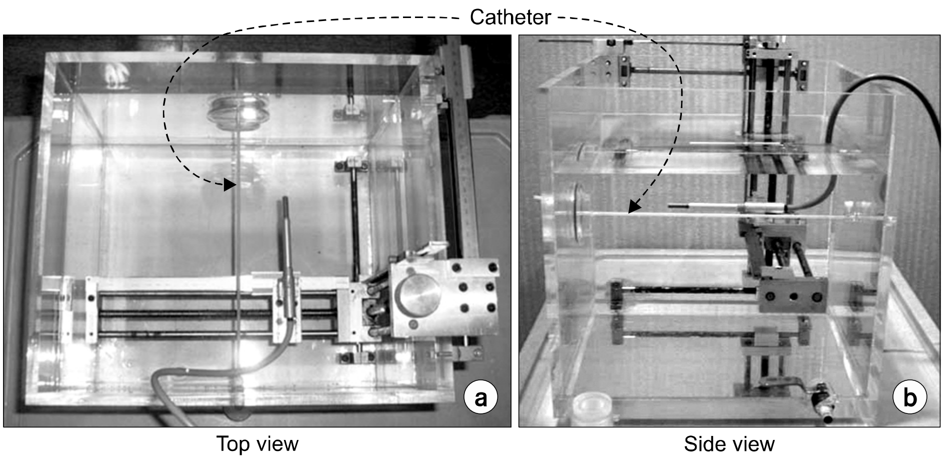

Fig. 4. The multipurpose phantom system developed for this work. The multipurpose phantom (MPBP) for brachytherapy sources only was designed. This MPBP enables a chamber to position at the distance you want from the center of the Ir-192 source.

^{192}Ir source has a broad spectrum ranging from about 61 keV to 1.4 MeV or so and therefore might be considered roughly to belong to low and medium energy range.

The individual k^{ind}_{Q,Q_0} for the particular chamber can be determined by equation (2) and (4).

$$k^{ind}_{Q,Q_0} = \frac{N_{D,W,Ir}}{N_{D,W,Co}} \qquad (10)$$

$$N_{D,W,Ir} = \frac{D^{Ir192}_{w}}{M^{Ir192}_{Q}} \qquad (11)$$

N_{D,W,C_0} is the calibration factor in terms of absorbed dose to water of the PTW 30013 chambers obtained from a standards laboratory at a reference beam quality ^{60}Co and $N_{D,W,Ir}$ the calibration factor obtained from measurements at an ^{192}Ir source. D^{Ir192}_{W}in equation (11) should be determined from direct measurements.

For this work the multipurpose brachytherapy phantom (MPBP) was home-made, which was designed to enable both sources and chambers positioned at the exact distance you want from the Ir-192 source in water phantom (Fig. 4). Ir-192 source moves through the fixed catheter and the chamber is positioned at the distance of 5 cm from the center of Ir-192 source.

Charge readings M^{Ir192}_{Q} in equation (11), which were corrected for temperature, air pressure, polarity effect, and ion recombination, were obtained using this phantom system. D^{Ir192}_{W} in equation (11) couldn't be determined directly because no primary or secondary standards for ^{192}Ir standard source are available . As an alternative for direct measurement with primary standards, the dose delivered by the RTP system was used as D^{Ir192}_{W}.

RESULTS AND DISCUSSION

Measurements were performed with five different serial numbers of PTW30013 ionization chambers, which were positioned at the same reference distance. An afterloading device with Nucletron HDR ^{192}Ir source were used in this measurements. Nucletron system delivered 15.0 cGy to the reference point and the dose to water delivered at the point were measured with 5 PTW30013 chambers and an UNIDOS electrometer.

1. The absorbed dose calculated with the generic value of k_{Q,Q_0}^{gen}

The data released by F.Ballester was used as the spectrum of ^{192}Ir source. 20 mCi, which amounts to 1,657,600,000 histories, were used for the ^{192}Ir source Monte Carlo simulation and one hundred million histories were used for the simulation of Co-60 beam irradiation.

The absorbed dose to water calibration factors of the PTW30013 chamber $N_{D,W,cobalt}$, and $N_{D,W,Ir192}$, in the Co-60 beam and ^{192}Ir source were calculated according to equation (8) and (9) with the uncertainty of ±0.3%.

$$N_{D,W,cobalt} = 5.17 \left[{cGy}/{nC} \right] \quad (12)$$

$$N_{D,W,ir192} = 5.25 \left[{cGy}/{nC} \right] \quad (13)$$

The beam qualtity correction factor k_{Q,Q_0}^{gen} of PTW30013 chamber is then calculated by equation (2)

$$k_{Q,Q_0}^{gen} = 1.015 \quad (14)$$

Now, the absorbed dos to water D_{mea}^{Ir192} in the ^{192}Ir brachytherapy source can be calculated with the calibration factor $N_{D,W,cobalt}$ calibrated in the ^{60}Co gamma ray beam by

$$D_{mea}^{Ir192} = N_{D,W,co60} \cdot k_{Q,Q_0}^{gen} \cdot M_Q^{Ir192} \quad (15)$$

$N_{D,W,Co}$s in Table 1 are the absorbed dose to water calibration factors of each chamber provided from KFDA (Korea Food & Drug Administration), which has the secondary standards of radiation dosimetry traceable to IAEA standard, in the ^{60}Co gamma ray, M_Q^{Ir192} the charge reading in unit of [nC] corrected for a temperature, an air pressure, a polarity effect, and an ion recombination, D_{ref} the dose delivered by RTP system at the position of an chamber in the absence of the chamber, and D_{mea}^{Ir192} the dose calculated by equation (15).

Protocols, as noted before, don't recommend to use generic values of k_{Q,Q_0}^{gen} in the low and medium energy X-ray. As expected from the recommendation, the absorbed doses calculated with the generic k_{Q,Q_0}^{gen} for 5 chambers show the difference of maximum 3% from the dose delivered by RTP system and chamber to chamber variations run up to maximum 4.0%.

If 5% could be, for example, accepted as the uncertainty extent of the determination of the dose in HDR brachytherapy source, the generic values of k_{Q,Q_0}^{gen} might be O.K to be used to determine roughly the dose in the HDR source. In order for the generic value of k_{Q,Q_0}^{gen} to make sense and useful to the determination of the dose, you could be sure that the data of chamber to chamber variations in the same chamber type should be first obtained from as many samples as possible, at least 10 or more and that the variations be within a certain acceptable level.

2. The absorbed dose calculated with the individual k_{Q,Q_0}^{ind} measured

The 5 different serial numbers of the PTW30013 chamber type were positioned at the reference distance of 5.0 cm from the center of the ^{192}Ir source and dwelled while the RTP system delivered 15.0 cGy to that position. This dose of 15.0 cGy was used as the measured dose D_W^{Ir192}-this is as a makeshift only an alternative for direct measurements with pri-

Table 1. Doses to water determined with the generic value of k_{Q,Q_0}^{gen} with the uncertainty of 0.3%. The errors in the last column represent the ratio of the dose D_{mea}^{Ir192} measured with chambers to the dose D_{ref} delivered by the RTP system.

Chamber (PTW30013)	$N_{D,W,Co}$ $\left[{nC}/{cGy} \right]$	M_Q^{Ir192} $[nC]$	D_{ref} $[cGy]$	k_{Q,Q_0}^{gen}	D_{mea}^{Ir192} $[cGy]$	Error (%)
1	5.437	2.8087	15.0	1.015	15.50	+3.33
2	5.328	2.8254	15.0	1.015	15.28	+1.86
3	5.296	2.8330	15.0	1.015	15.23	+1.53
4	5.405	2.7692	15.0	1.015	15.19	+1.28
5	5.408	2.7205	15.0	1.015	14.93	−0.45

Table 2. Doses to water determined with the individual value of k_{Q,Q_0}^{ind} with the uncertainty of ±0.3%. The errors in the last column represent the ratio of the dose D_{mea}^{Ir192} measured with chambers to the dose D_{ref} delivered by the RTP system.

Chamber (PTW30013)	$N_{D,W,Co}$ $[nC/cGy]$	M_Q^{Ir192} $[nC]$	D_{ref} $[cGy]$	$N_{D,W,Ir}$ $[nC/cGy]$	k_{Q,Q_0}^{ind}	D_{mea}^{Ir192} $[cGy]$	Error (%)
1	5.437	2.8087	15.0	5.415	0.996	15.000	+0.000
2	5.328	2.8254	15.0	5.383	1.010	14.995	−0.033
3	5.296	2.8330	15.0	5.369	1.014	15.004	+0.027
4	5.405	2.7692	15.0	5.492	1.016	14.997	−0.020
5	5.408	2.7205	15.0	5.591	1.034	15.003	+0.020

mary/secondary standards- in equation (11) for the calculation of the absorbed dose to water calibration factor $N_{D,W,Ir}$ of the individual chambers in the ^{192}Ir source.

The individual values of k_{Q,Q_0}^{ind} for the each chamber were then calculated from equation (10). The absorbed dose to water D_{mea}^{Ir192} at the reference distance of 5.0 cm from individual chambers were then calculated from the following equation.

$$D_{mea}^{Ir912} = N_{D,W,co60} \cdot k_{Q,Q_0}^{ind} \cdot M_Q^{Ir192} \qquad (16)$$

The semiexperimentally measured k_{Q,Q_0}^{ind} values for 5 different serial numbers of an PTW30013 chamber type were in the range of 0.996 to 1.034. The absorbed doses calculated with those k_{Q,Q_0}^{ind} values were in a good agreement within 0.3%with the dose delivered by the RTP system and the chamber to chamber variations were within a maximum deviation of 0.5%. Small variations between chambers in Table 2 show that protocols based on absorbed dose to water standards be good and easy methods for the calibration of ^{192}Ir brachytherapy sources only if chambers could be individually calibrated.

CONCLUSION

It is of course sure that the factor k_{Q,Q_0} from this method be not as accurate as calculated by primary standards. That is to say, this study bears an intrinsic limitation that the dose by RTP system instead of the direct measurements were used for the calculation of $N_{D,W,Ir}$.

Nevertheless, the result shown in the Table 2 gives users hopeful hints that this kind of trials done in this work might be an alternative for the calibration of ^{192}Ir brachytherapy sources based on absorbed dose to water standards in the situation where primary standards are nonavailable and stresses how important the individual calibrations of ionization chambers are for the calibration of ^{192}Ir brachytherapy sources.

We hope that in the near future primary standards dedicated to the calibration of the brachytherapy sources based on absorbed dose to water be developed in Korea and that users will be able to calibrate the brachytherapy sources in terms of an absorbed dose to water, the quantity of interest in the treatment, instead of an air kerma strength just as the calibration in the high energy photon and electron beam.

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물흡수선량 표준에 기반한 ^{192}*Ir* 근접치료 선원 교정 시 원통형 이온함의 이온함 간 변화

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본 논문은 물 흡수선량 표준에 기반하여 근접치료 선원인 ^{192}*Ir*을 교정하는 것에 대한 예비적 연구를 위한 것이다. 이온함을 사용하여 물흡수선량 표준에 기반하여 근접치료 선원을 교정하기 위해선, 빔 선질 교정인자인 k_{Q,Q_0}가 필요하다. 본 연구에선 일차 표준을 사용하여 지정된 거리에서의 흡수선량를 측정하는 데 있어서의 현실적인 어려움 때문에 몬테칼로 전산모사와 반실험적인 방법을 통하여 k_{Q,Q_0}를 결정하였다. 본 연구를 위해 PTW30013 이온함 5개를 선택하였다. 포괄적 k^{gen}_{Q,Q_0} 값의 경우엔 이온함간 변화가 최대 4.0%에 이른 반면, 개별적 k^{ind}_{Q,Q_0} 경우엔 이온함간 변화가 최대 0.5% 이내였다. 이 결과는 물 흡수선량에 기반하여 근접치료 선원인 ^{192}*Ir*을 교정시에 이온함을 왜 개별적으로 교정해야 하는지, 개별적인 교정이 얼마나 중요한 지를 보여 준다. 가까운 장래에 공기커마 세기 대신에 사용자가 근접치료 선원을 고에너지 광자빔과 전자빔의 교정에서처럼 치료에서 관심있는 물리량인 물흡수선량의 관점에서 교정할 수 있기를 희망한다.

중심단어: 빔선질 교정인자, 물흡수선량, 이온함, 일차 표준